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**SHORT TERM WEATHER FORECASTING IN REAL  
TIME IN A BASE WEATHER STATION SETTING****Frank P. Colby, Jr.  
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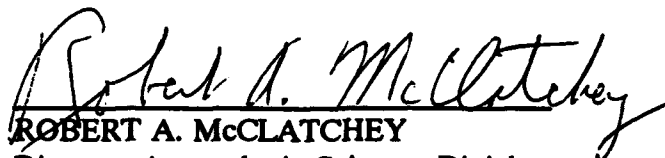
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## 1. Introduction

This year of effort was spent primarily on making changes to the initialization routines, the boundary conditions, as well as making a few changes to the model itself. The single most important change to the model was the addition of clouds and precipitation, albeit in a somewhat simplistic manner. The results of this change were not universally positive, but in the process of making these additions, problems with the initialization and boundary conditions became apparent. Thus, a significant part of the effort has been absorbed with dealing with these issues.

We would like to point out that both the initialization and the time-dependent boundary conditions would likely be improved with the use of National Weather Service gridpoint data. As an economy measure, this data service was discontinued at Phillips Laboratory at Hanscom AFB. Both we and Phillips Laboratory personnel are pursuing alternate sources. The expense of obtaining this service ourselves has prevented us from struggling with this data directly. The result is that we are still using actual rawinsonde data from the conventional data available to us to determine both initial conditions and the boundary conditions for the various model runs. Thus, the model is still being run in a case-study mode, rather than in a true forecast mode.

## 2. Initialization

During our analysis of some cases, we discovered that the initial fields were much smoother than they should be. Because the coarse grid extends over the Atlantic Ocean, where data is sparse, the Gempak analyses had to be run in a coarse mode, causing unrealistic smoothing. We needed a method which would give additional "data" points in the ocean without requiring us to generate fake data. The new initialization is done in two steps.

The initial analysis is done using the coarse gridding parameters as before, but the values over the water are then determined at specific points, given fake station id numbers, and put into the database which has the real station data in it. The Gempak analysis is repeated, using smaller scale parameters, resulting in more detail in the initialization. This analysis works with the expanded "data", but the values used for the fake stations are as good as the initial analysis could determine, and the entire process is done automatically. We have extended this process to other data-sparse regions in the coarse mesh. Figure 1a shows the original data points, and Figure 1b shows the complete set with the fake stations. It is clear that the fake stations provide a much more continuous data set, thus allowing the automatic initialization to be set for detailed analysis.

The results are shown in Figures 2, 3 and 4 for a December model run. Figure 2 shows the old, smooth initialization. It is somewhat remarkable and a tribute to the theory behind the model itself that the complicated fields shown in previous reports can grow from such a smooth initial temperature field. Obviously, the varying terrain and differential development of the boundary layer controls much of what happens during the subsequent day. Figure 3 shows the more detailed initialization, and Figure 4 the real data. It is quite clear that the detailed initialization in Figure 3 has captured almost every detail of the real data field. The only feature missed is the small bubble of minus 4°C temperatures extending from the northern end of Long Island towards the southeast. Thus, where the fake stations are located, the analysis is smooth, but where there is real data, the analysis incorporates all the

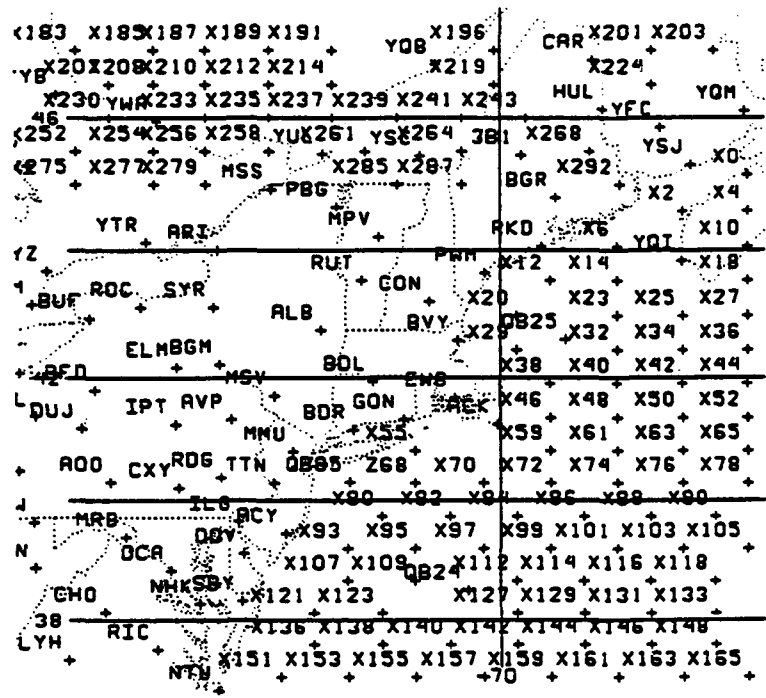
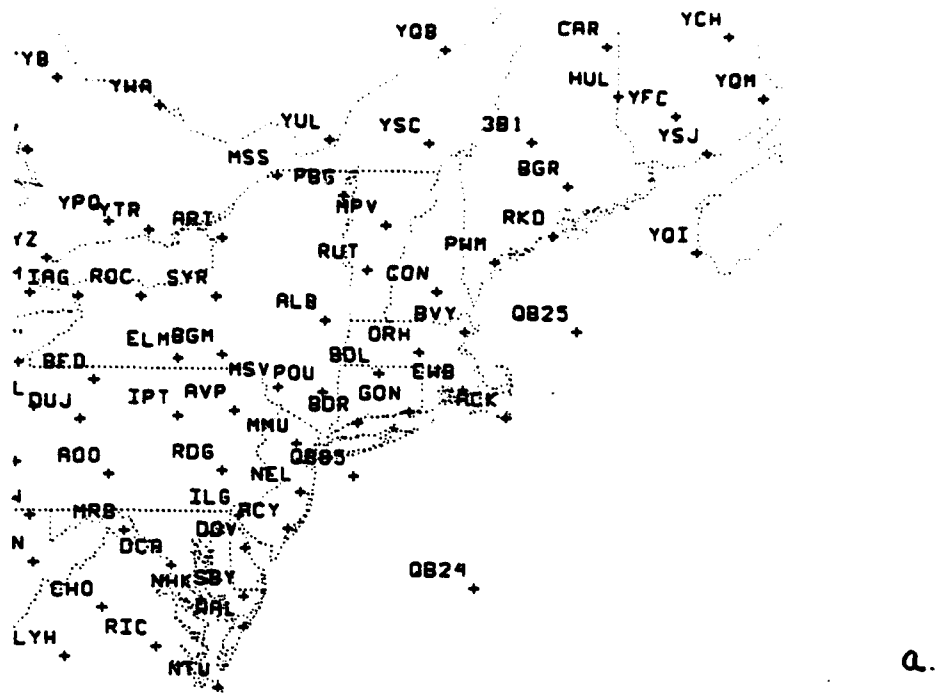


Figure 1. a) shows station ids for observations, b) shows the augmented set (see text for details).

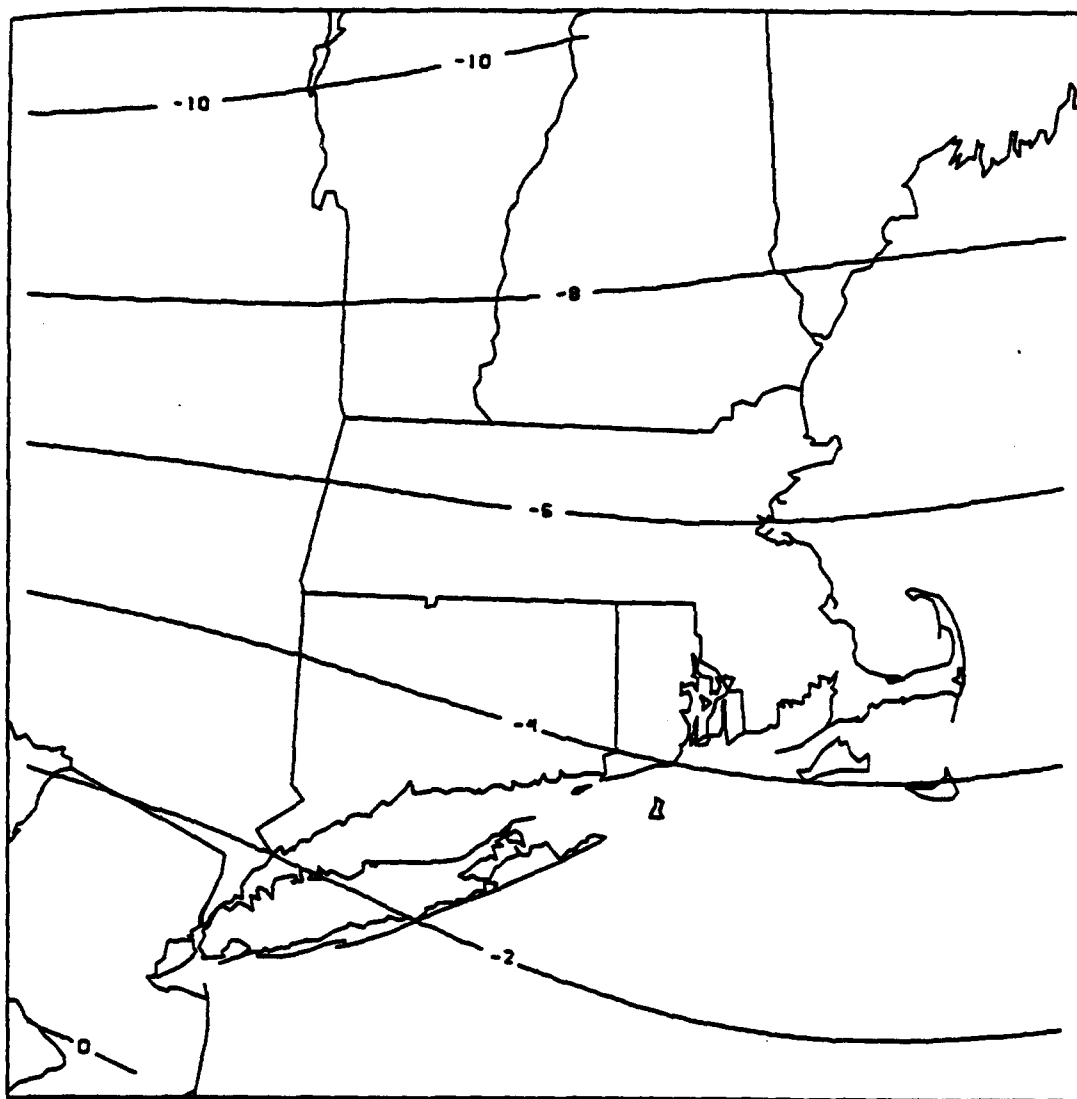


Figure 2. Initial temperature field (C), smooth version for fine mesh.



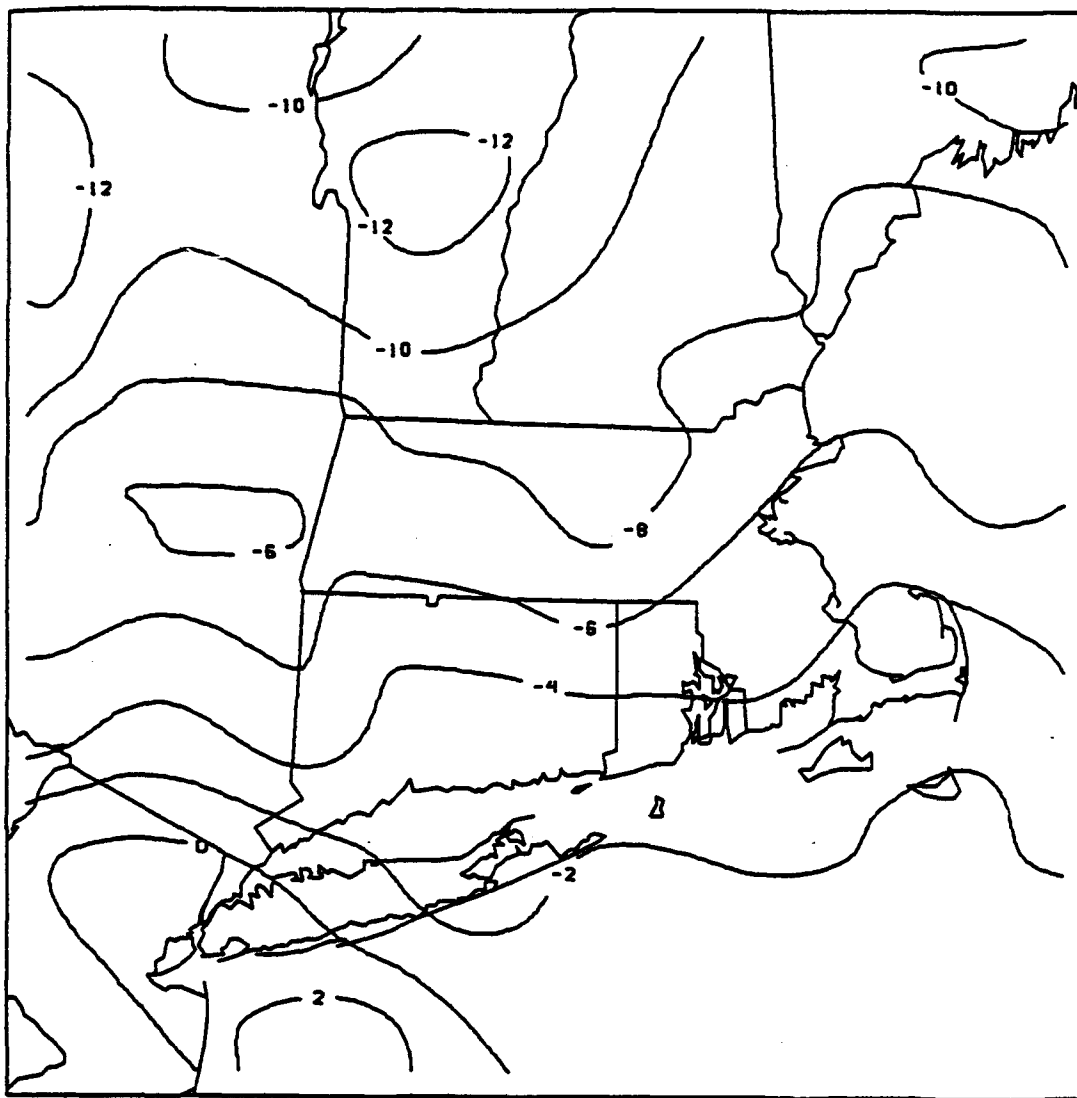


Figure 3. As in Figure 2, except for more detailed initialization.

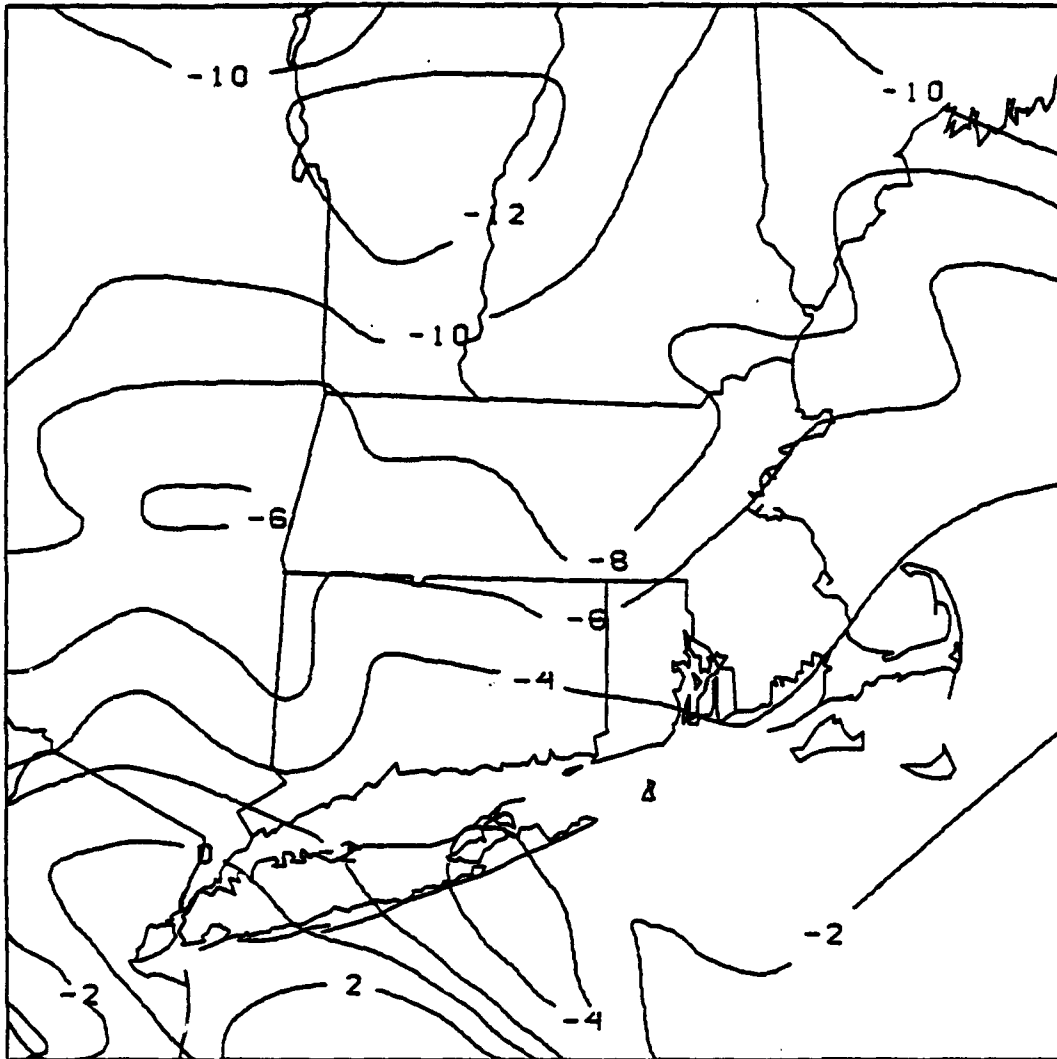


Figure 4. Initial temperature field taken from actual data for December case.

available detail. The subsequent changes which take place in the model are quite different at times between the smooth and detailed initializations. For example, in Figures 5 and 6, the temperatures after 6 hours of simulated time are shown. The character of the field in the northeastern corner is quite different, and the temperatures in the middle of the domain are about 2°C colder in the run with the detailed initialization. We believe this difference to be due to the colder initial temperatures as seen in Figure 2, causing the heating to be delayed a bit. Oddly, after 9 hours of simulation, these differences have mostly disappeared. The noisy nature of the field in the smooth case, Figure 7, is reduced in the detailed initialization, Figure 8. The temperatures in the middle of the domain, however, are largely the same. We suspect that the development of the boundary layer is controlling this aspect; both versions eventually get to the same stage, it just took longer with the detailed initialization. The rest of the integrations show no significant differences, confirming this conclusion.

### 3. Wind Initialization

The initial wind field for the model is specified using surface and upper air pressure gradients. Geostrophic winds are calculated from these gradients, and these winds are used as the initial winds in the model. Using Gempak to specify the initial fields, the gridded data is taken from a larger area to ensure that the edges are correctly specified. This resulted in having height/pressure data only to the edges of the coarse mesh, which meant that the winds were impossible to compute right on the boundary. Until now, we have simply extrapolated the interior winds one grid point outwards to the edges.

With our desire to provide time-variable winds along the

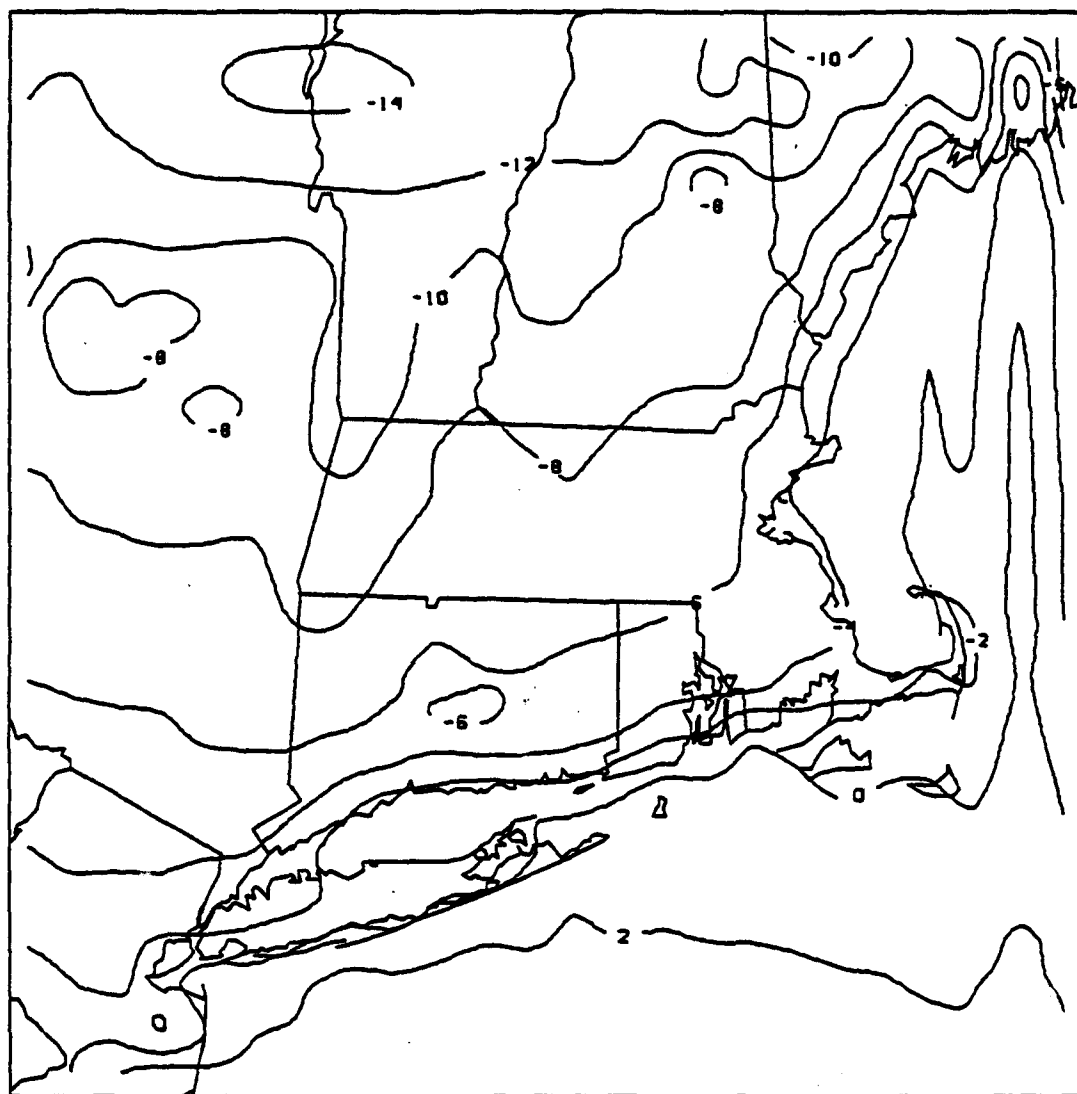


Figure 5. Temperature field after 6 hours of simulation, for the smooth initialization.

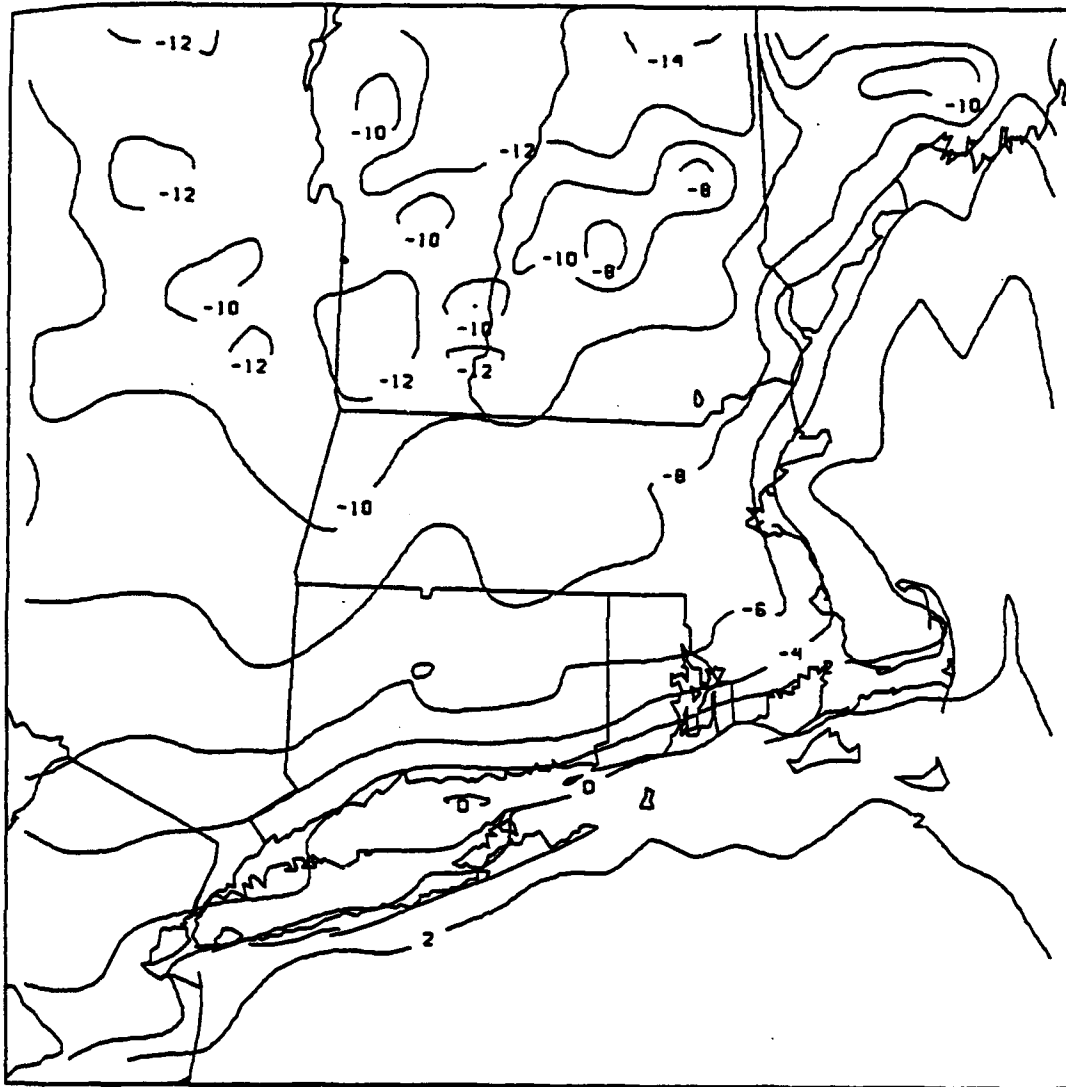


Figure 6. As in Figure 5, except for the detailed initialization.

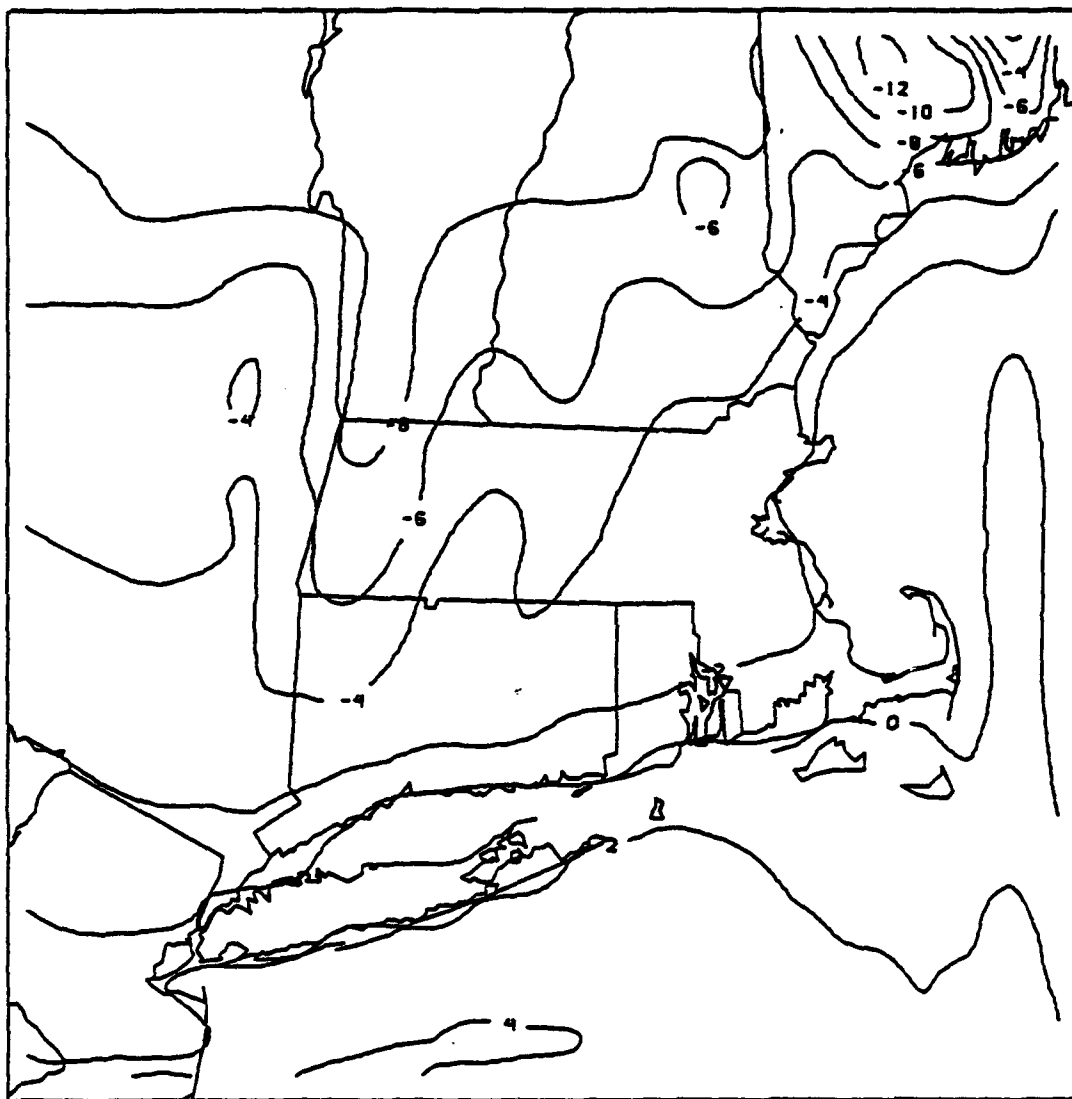


Figure 7. As in Figure 5, except after 9 hours of simulation.

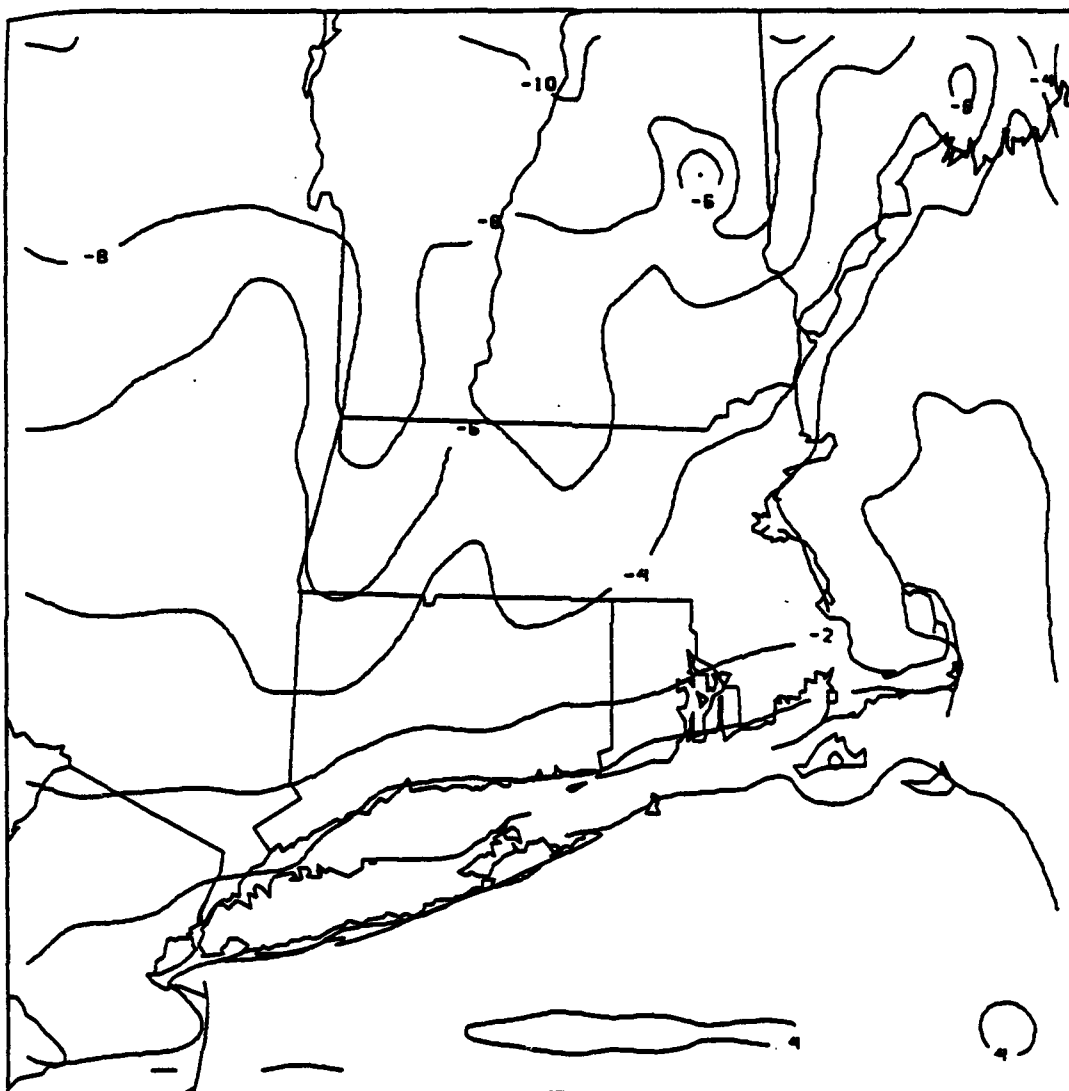


Figure 8. As in Figure 6, except after 9 hours of simulation.

boundaries, we realized that this process would be facilitated if we could use an extended grid for the heights/pressures, and thereby be able to actually compute winds on the edges, eliminating the extrapolation. We didn't expect the model to be too sensitive to a change in just the outermost grid points of the coarse mesh, but we were wrong. Figure 9 shows the model output for a May case after 10 hours of simulation using the old initialization, while Figure 10 shows the model with the new initialization. In many respects, the two figures are very similar to each other, but noticeable differences include: in the northeast the new version shows a cold pool just off the coast of Maine, a feature absent in Figure 9, in the southeast the temperatures over water are much warmer in the new version compared with the old version. Other subtle differences are apparent as well. Figures 11 and 12 show the surface pressure and boundary layer winds; again the differences are clear.

An interesting question to ask at this point is, "Which is a better forecast?". The answer for this one case is that the new version is clearly better. The cold pool off Maine appears in the real data at the same time as the model, and the cool air moves south across New England correctly in the new version as well. Figure 13 shows the temperature difference field between the new and old versions after 4 hours of simulation. Already some differences are showing up, and after 7 hours (Figure 14), the cool pool in the northeast is evident. After 16 hours of simulation, the difference field is largest in magnitude (Figure 15) with the new version as much as 8°C colder just off Massachusetts, and portions of Maine 8 to 12 °C warmer. Comparing with the real data, the colder simulation is much closer to reality.



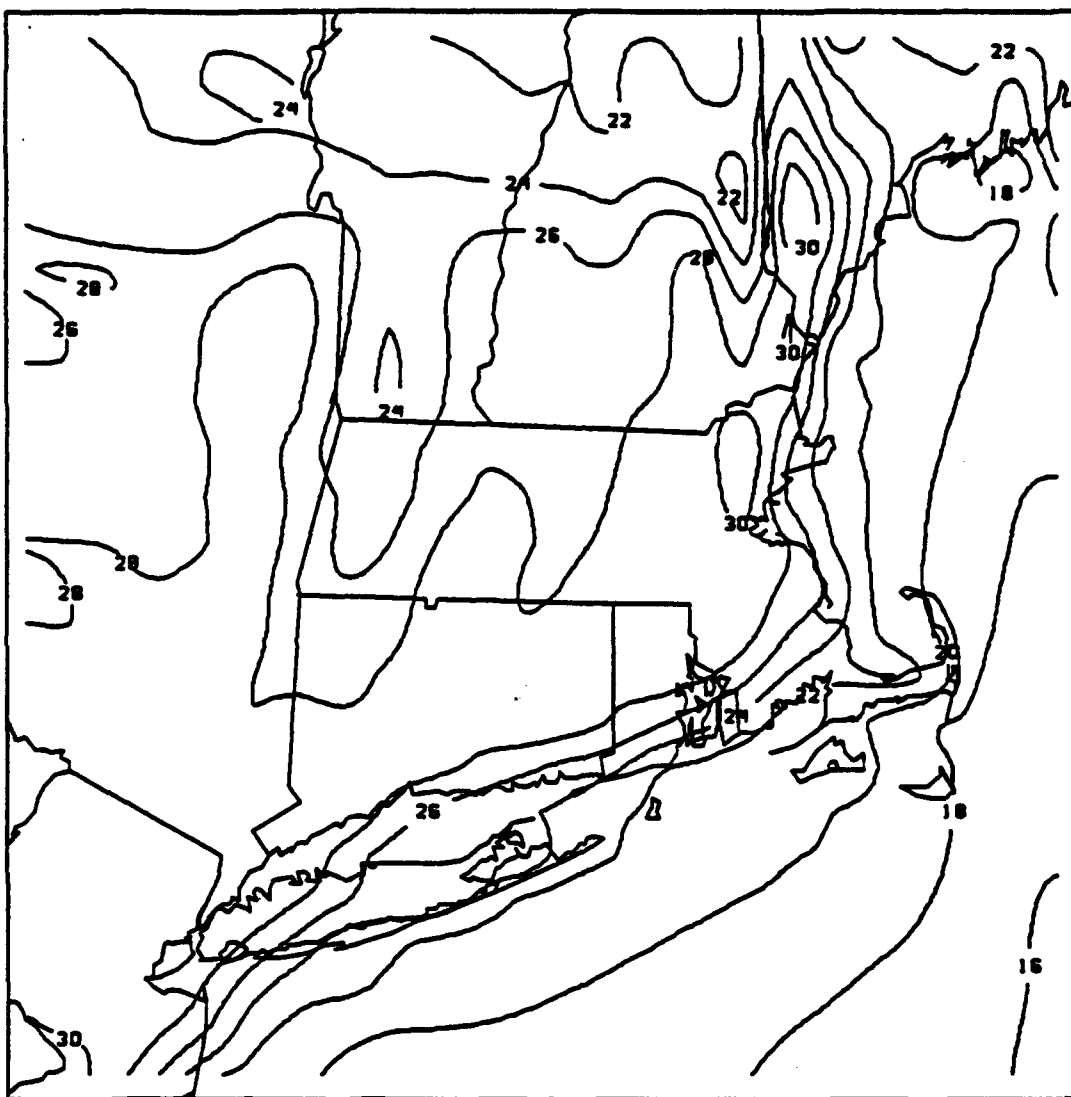


Figure 9. Fine grid mesh model output of temperatures ( C) after 10 hours of simulation, using the old initialization.

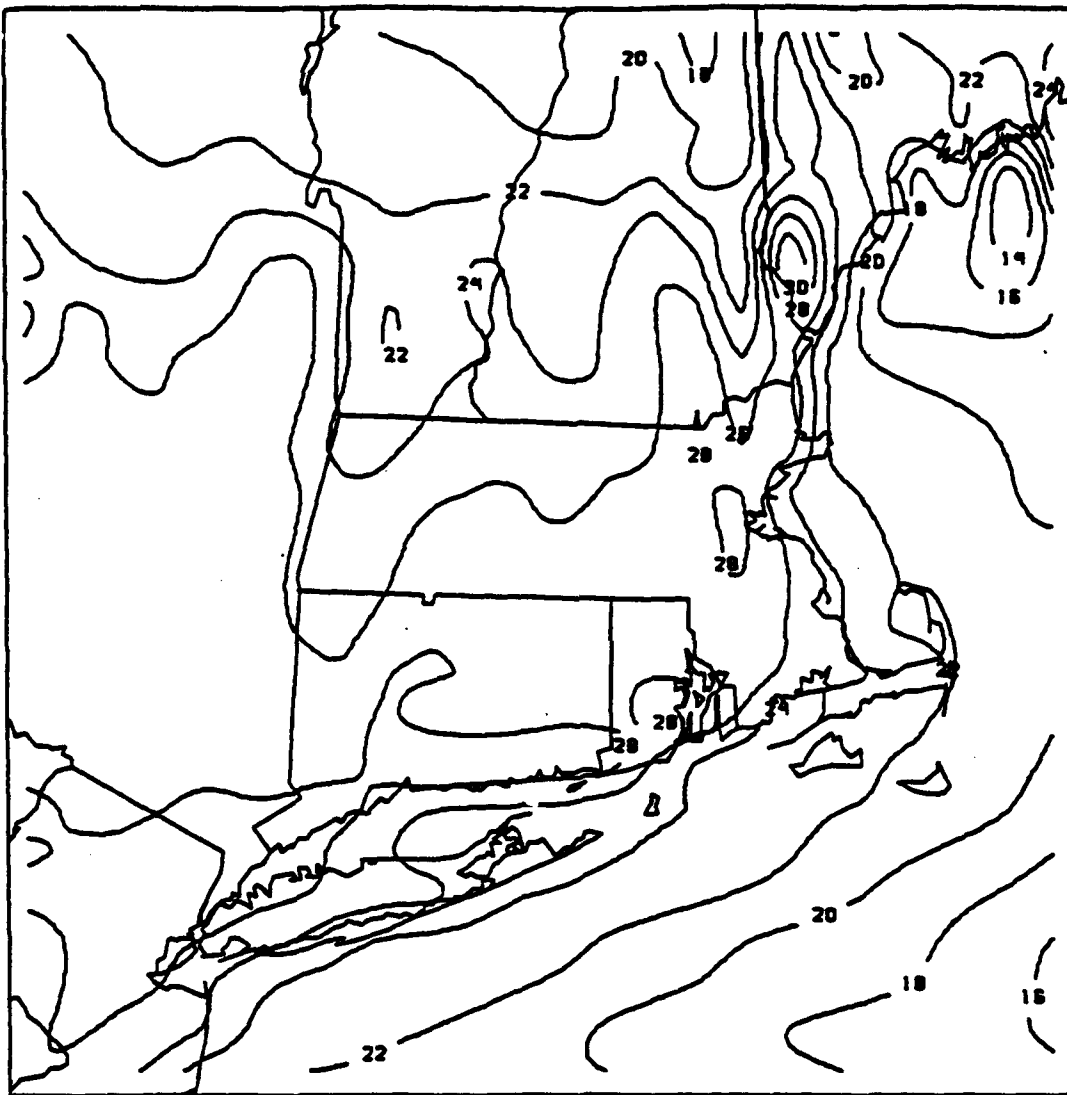


Figure 10. As in Figure 9 except using new initialization.

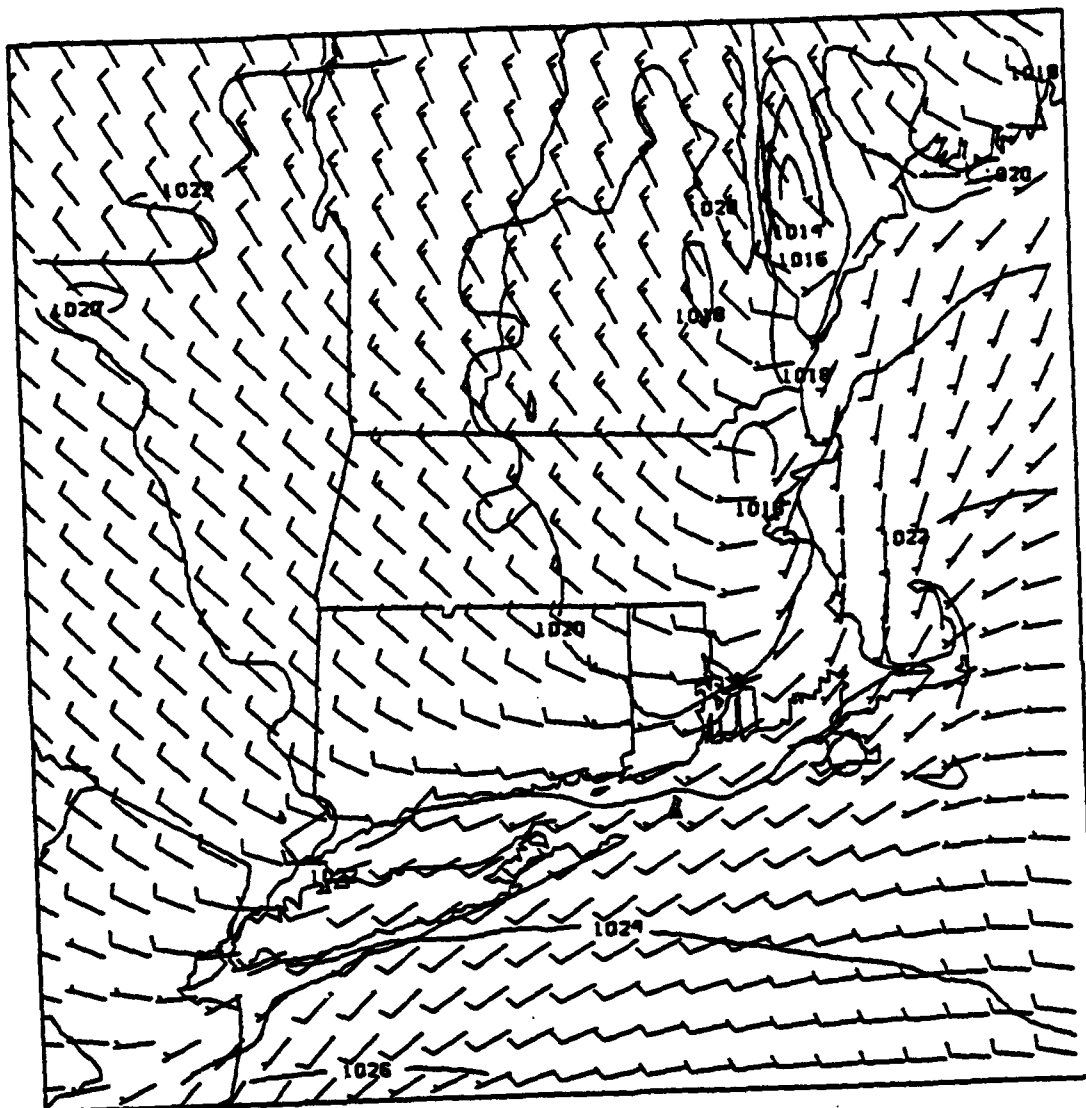


Figure 11. As in Figure 9, except showing surface pressure (mb) and boundary layer winds (knots - conventional plotting).

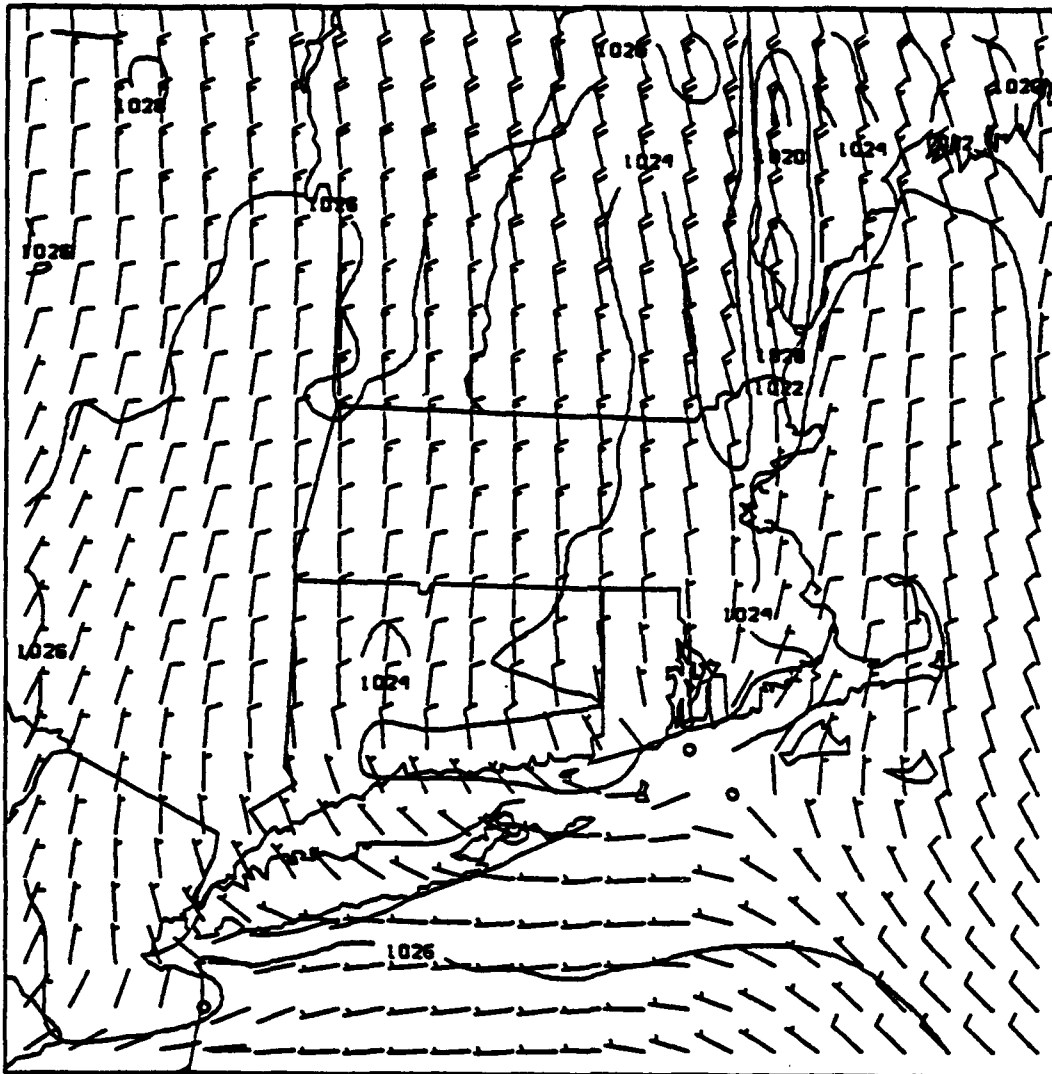


Figure 12. As in Figure 11 except for new initialization.

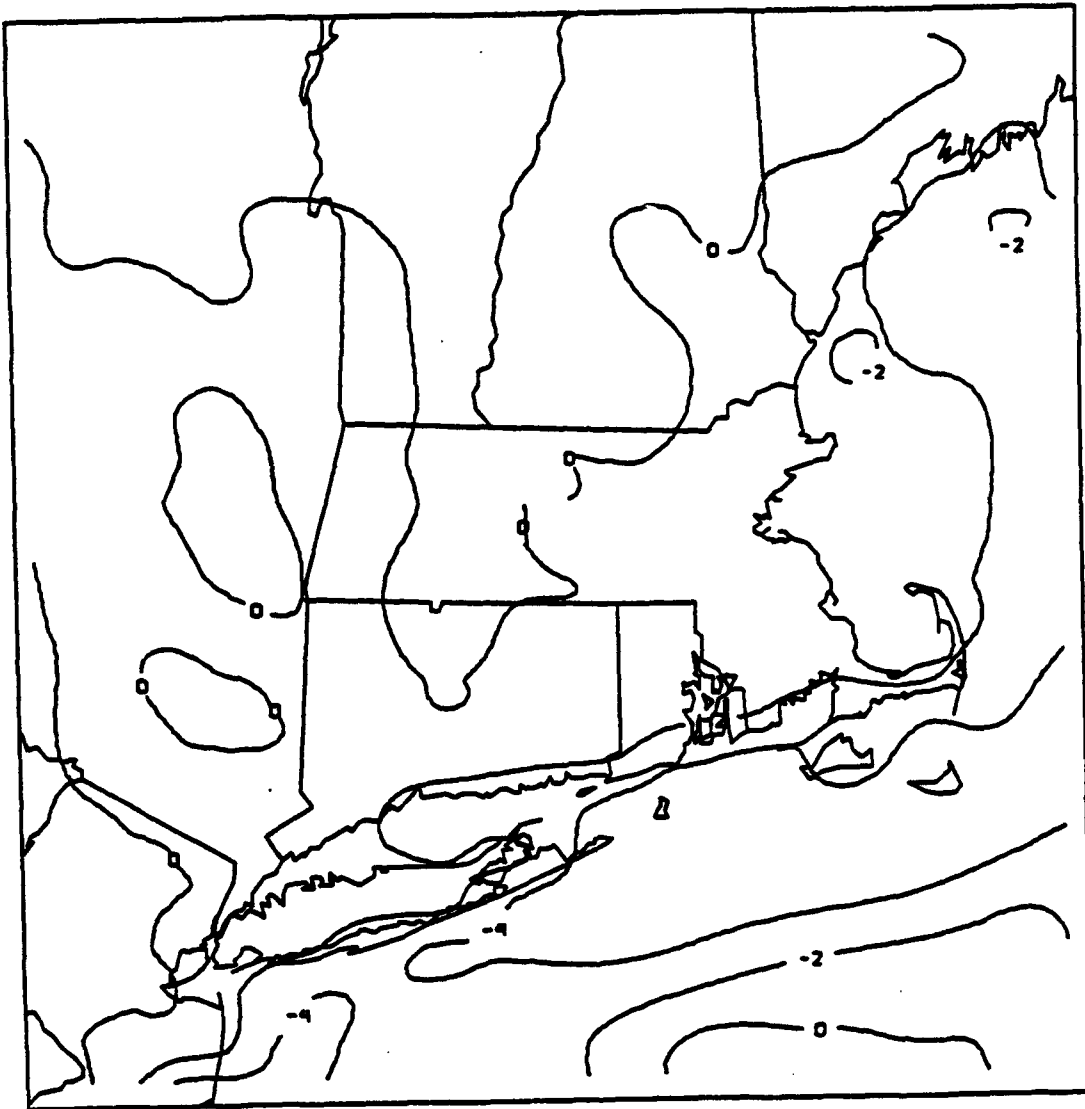


Figure 13. Temperature difference ( C) between new and old initialization runs after 4 hours of simulation.

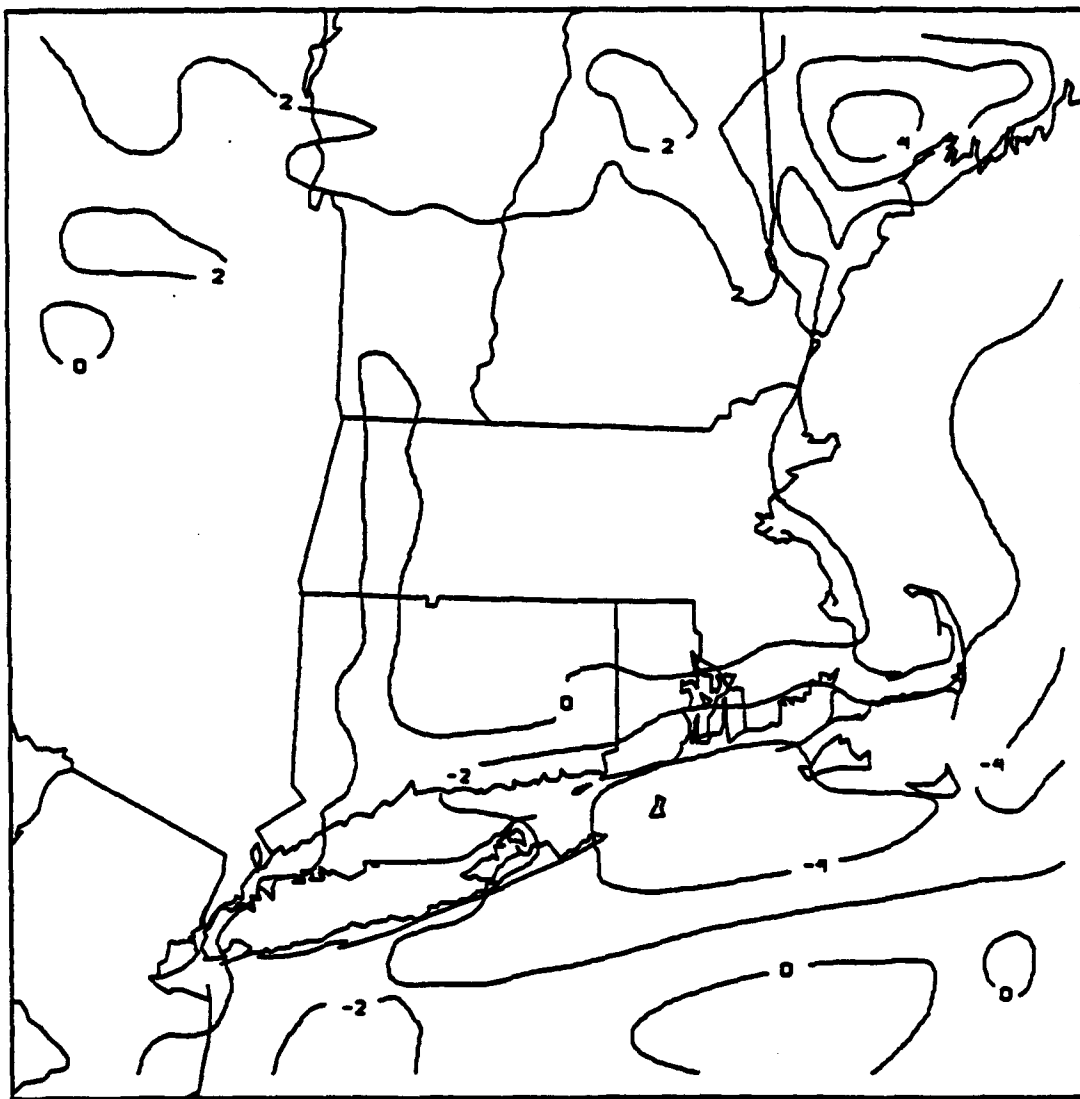


Figure 14. As in Figure 13, except after 7 hours of simulation.

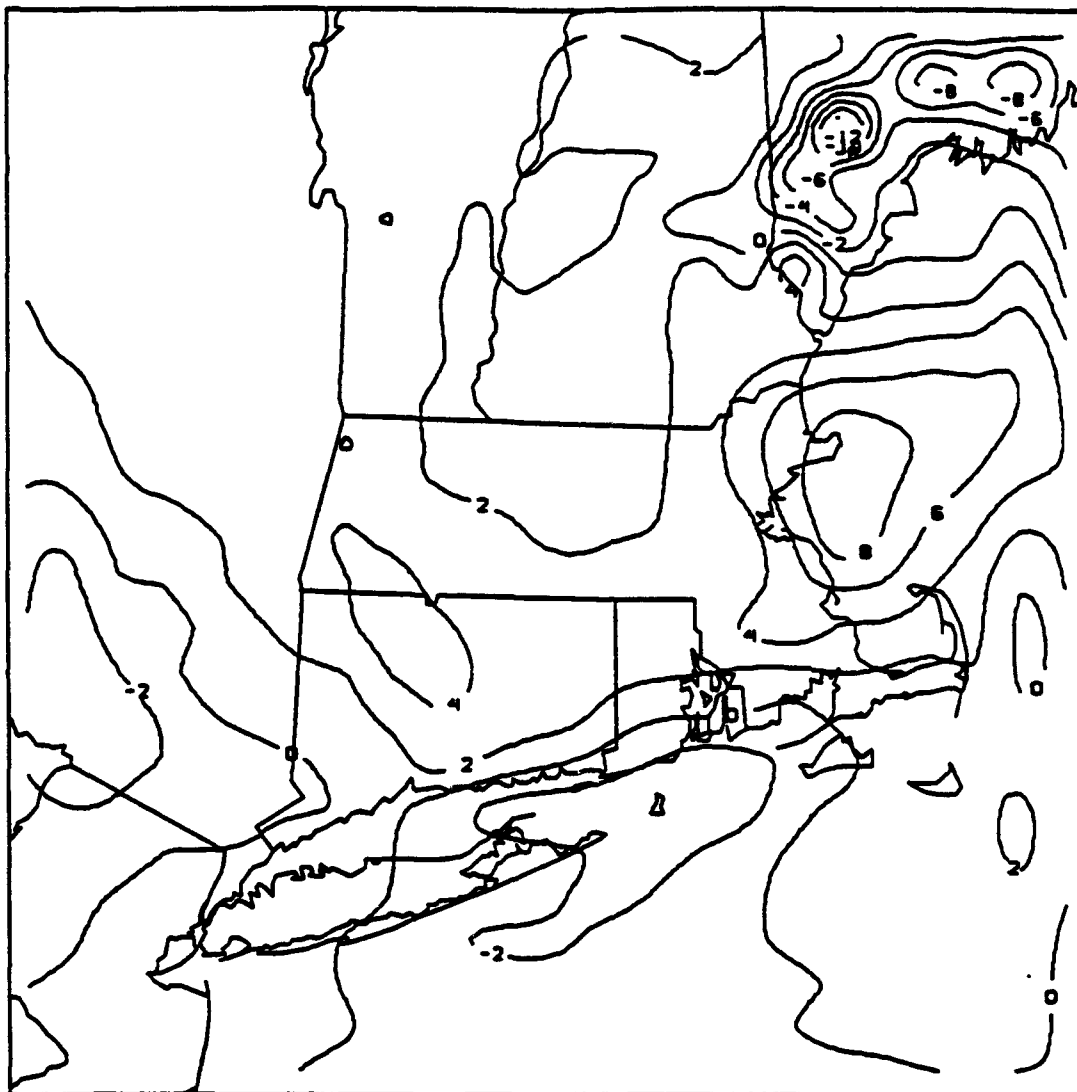


Figure 15. As in Figure 13, except after 16 hours of simulation.

#### 4. Wind Tendency

Having made the changes in the initialization, we were able to add variable boundary wind conditions, similar to what we do with temperature and moisture. The coding for this took some time to develop. Initially, we tried computing the u and v components at sounding times (12 hours apart), then interpolating the components over time to obtain the winds. These winds could then be used in the model. The model was unstable with this plan. Instead, we interpolate the heights in time along the boundaries, compute the winds, and then interpolate the components to the model surfaces. This seems to be stable, and offers the additional benefit of making it simpler to change from geostrophy to a more sophisticated balance condition in the future.

Figure 16 shows the temperature field after 10 hours of simulation, and Figure 17 shows the 850mb winds and surface pressure (compare with Figures 10 and 11). Certainly the fields are quite different, and the cool pool is once again missing from the northeast. Although the tendency winds obviously changed the model run, it isn't clear whether the change is in the right direction. Recent work demonstrates that the use of tendencies always results in a better simulation, as long as the boundary condition data are of good quality.

#### 5. Clouds

We have included complete cloud layers in test runs of the model, and obtained results which simply confirmed the model's ability to handle radiation and boundary layer growth. We now allow clouds to be interactive within the model. The amount of cloud in a given model layer is determined



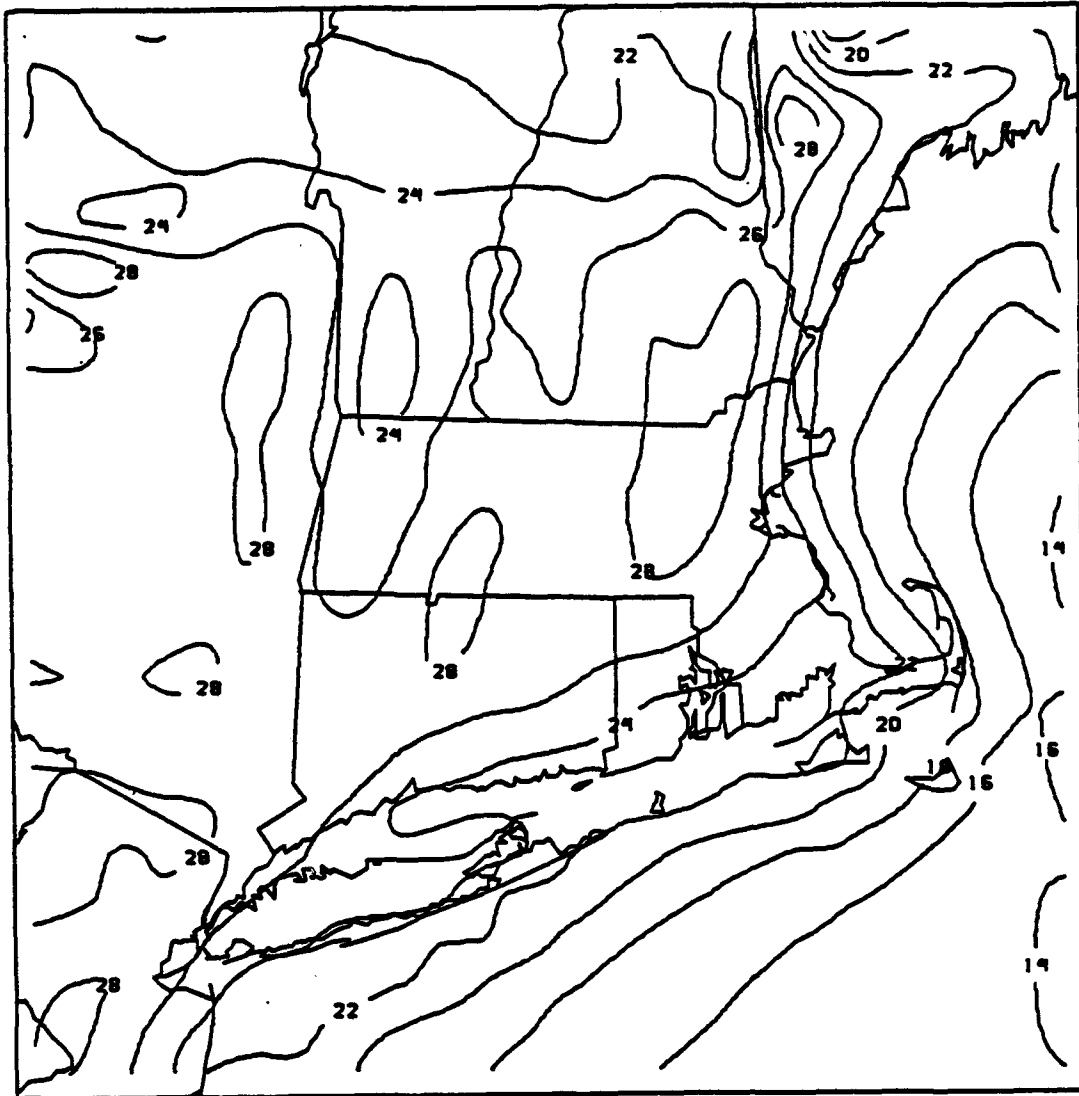


Figure 16. Fine grid mesh model output of temperatures ( $^{\circ}\text{C}$ ) after 10 hours of simulation using time-variable wind tendencies.

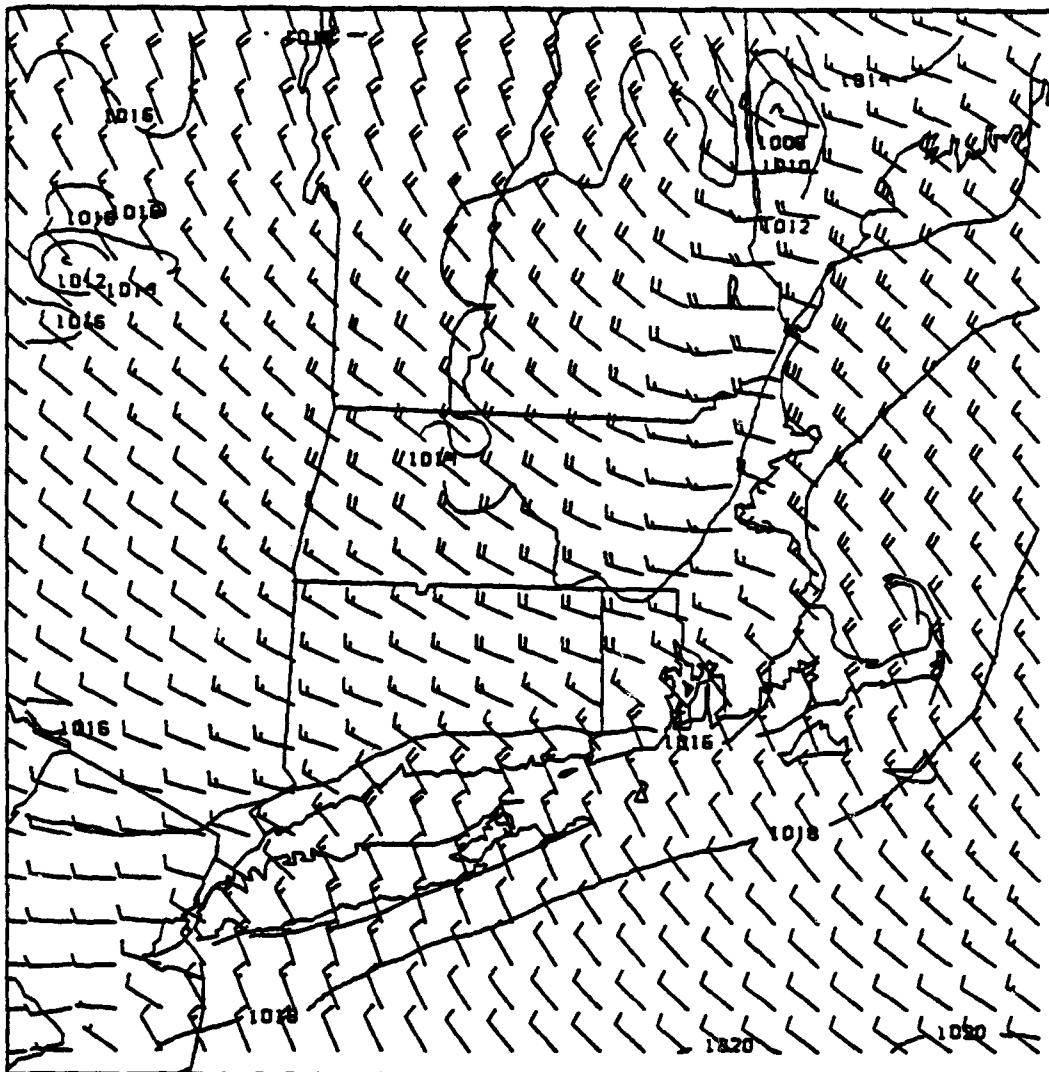


Figure 17. Fine grid mesh model output of sea-level pressure and 850mb winds after 10 hours of simulation using time-variable wind tendencies.

by a relatively simple formula, based on the average relative humidity in the layer. The formula is:

$$\text{GREY} = \min(1.00, 6.25(1.00 - \text{RH})^2)$$

This allows the amount of cloud to grow from 0 to 100% beginning at 60% relative humidity. Notice that the variable GREY above is 1.0 for clear skies and 0.0 for completely cloudy skies. Figure 18 shows a graph of the variable GREY as a function of the relative humidity.

The amount of clouds occurring in the generic May case used for these comparison runs is not large, but the effects are significant. After 2 hours of simulation, the cloud amounts in the model are shown in Figure 19. The model output for a run without clouds after 4 hours is shown in Figure 20, while the temperatures for the run with clouds are shown in Figure 21. Notice that the run with clouds is cooler by 2 to 4 degrees throughout MA, and southern NH and VT. The cloud cover in NH and VT clearly restricted the heating there, while the northerly winds flowing from that region cooled MA. This same kind of behavior continues throughout the model run, except that as the boundary layer warms, the lower clouds dissipate, and the differences become less pronounced. After 10 hours of simulation, the two runs, as shown in Figures 22 and 23, are almost identical, except where clouds had persisted in southernmost ME.

## 6. Precipitation -- Model Equation

Precipitation in the model is handled in a crude fashion. Any supersaturation that is detected in a layer above the boundary layer (excluding the topmost layer) is removed and accumulated at the ground as precipitation.

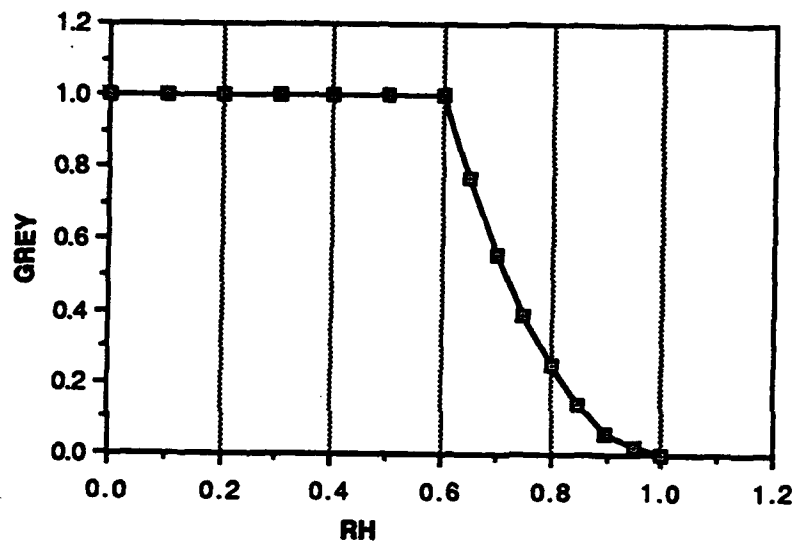


Figure 18. Graph of model variable GREY as a function of relative humidity.

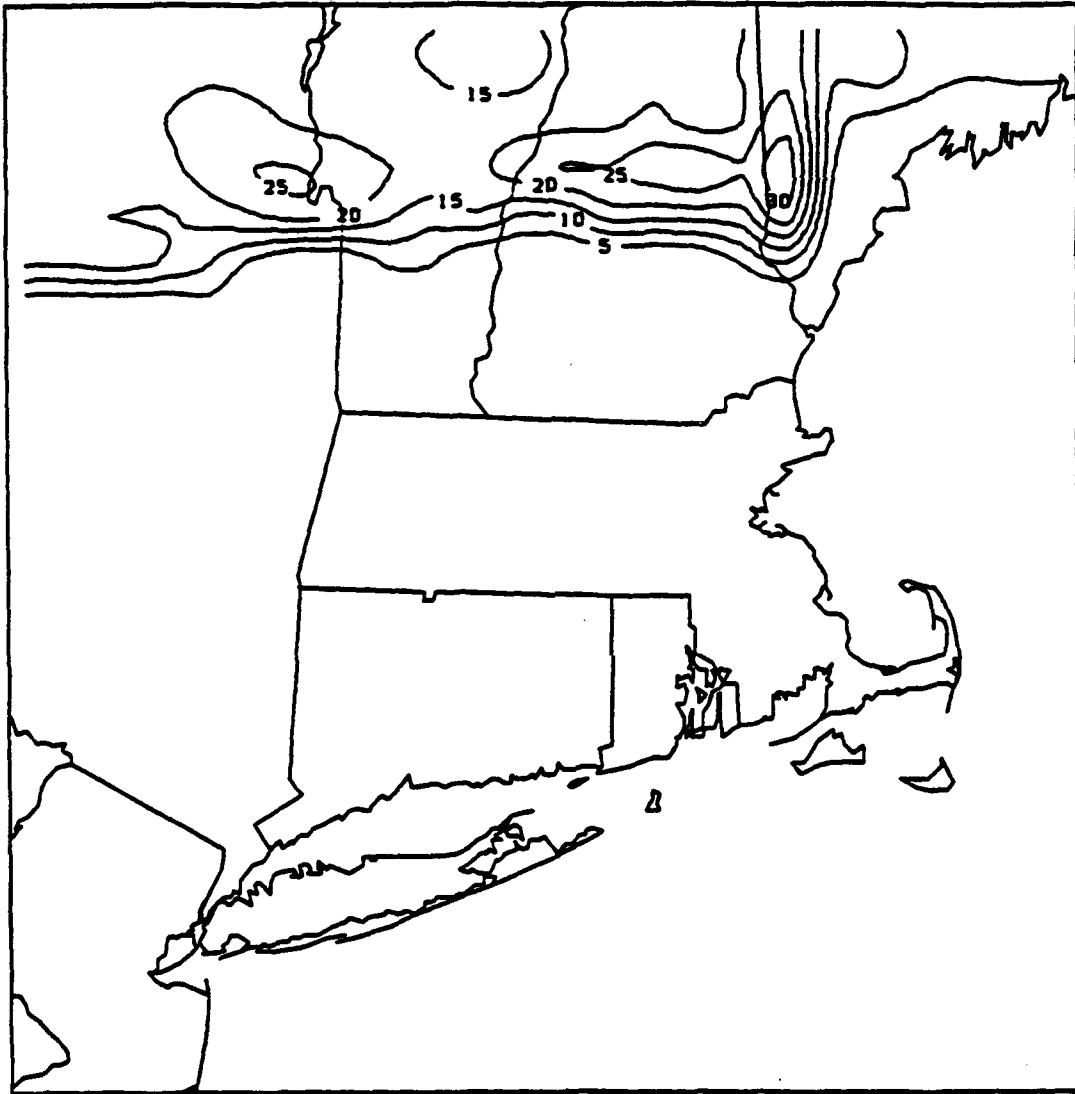


Figure 19. Integrated cloud amount from 3 layers above the boundary layer after 2 hours of simulation over fine grid mesh.

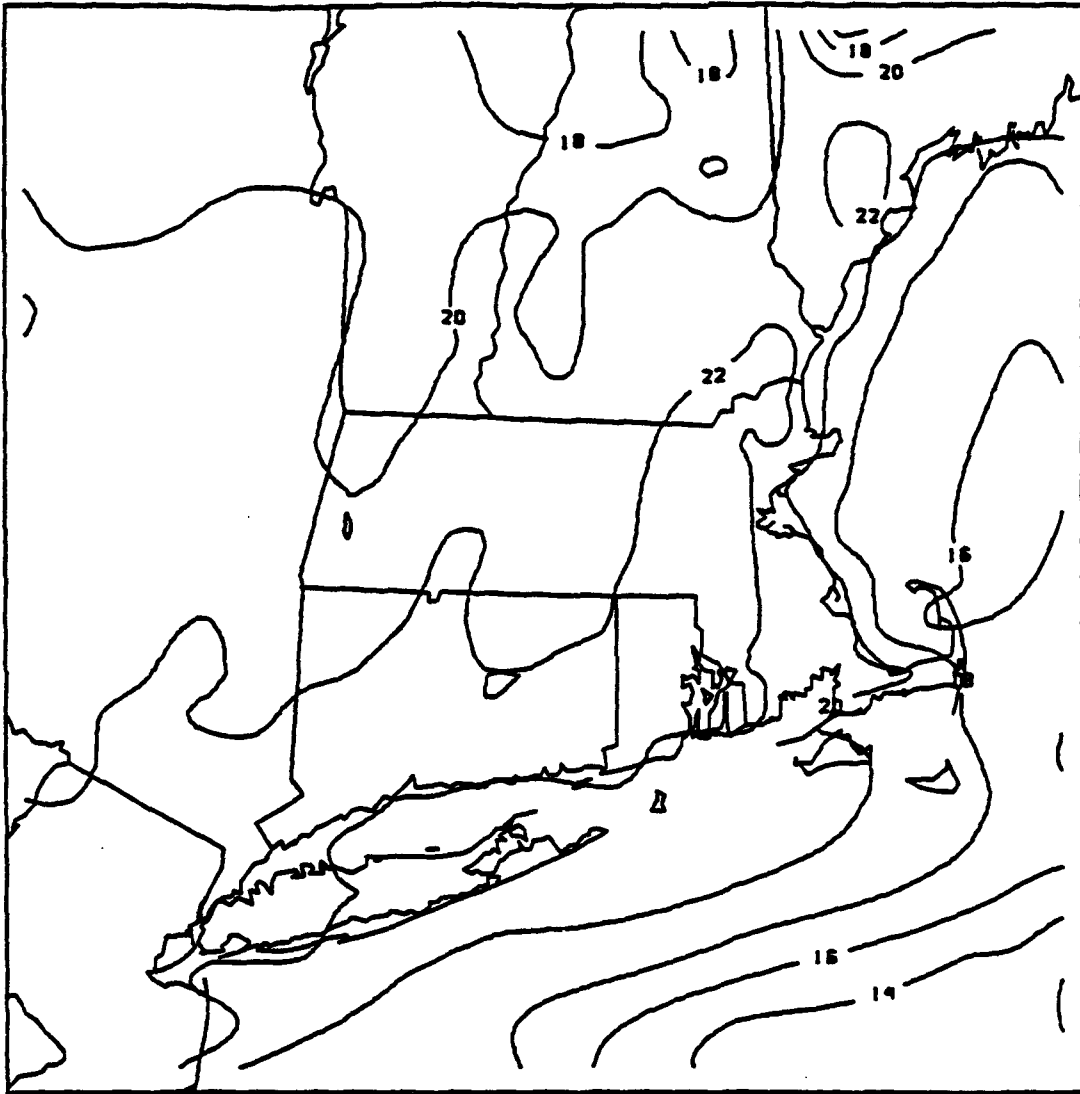


Figure 20. Fine grid mesh model output after 4 hours of simulation for model run without clouds.

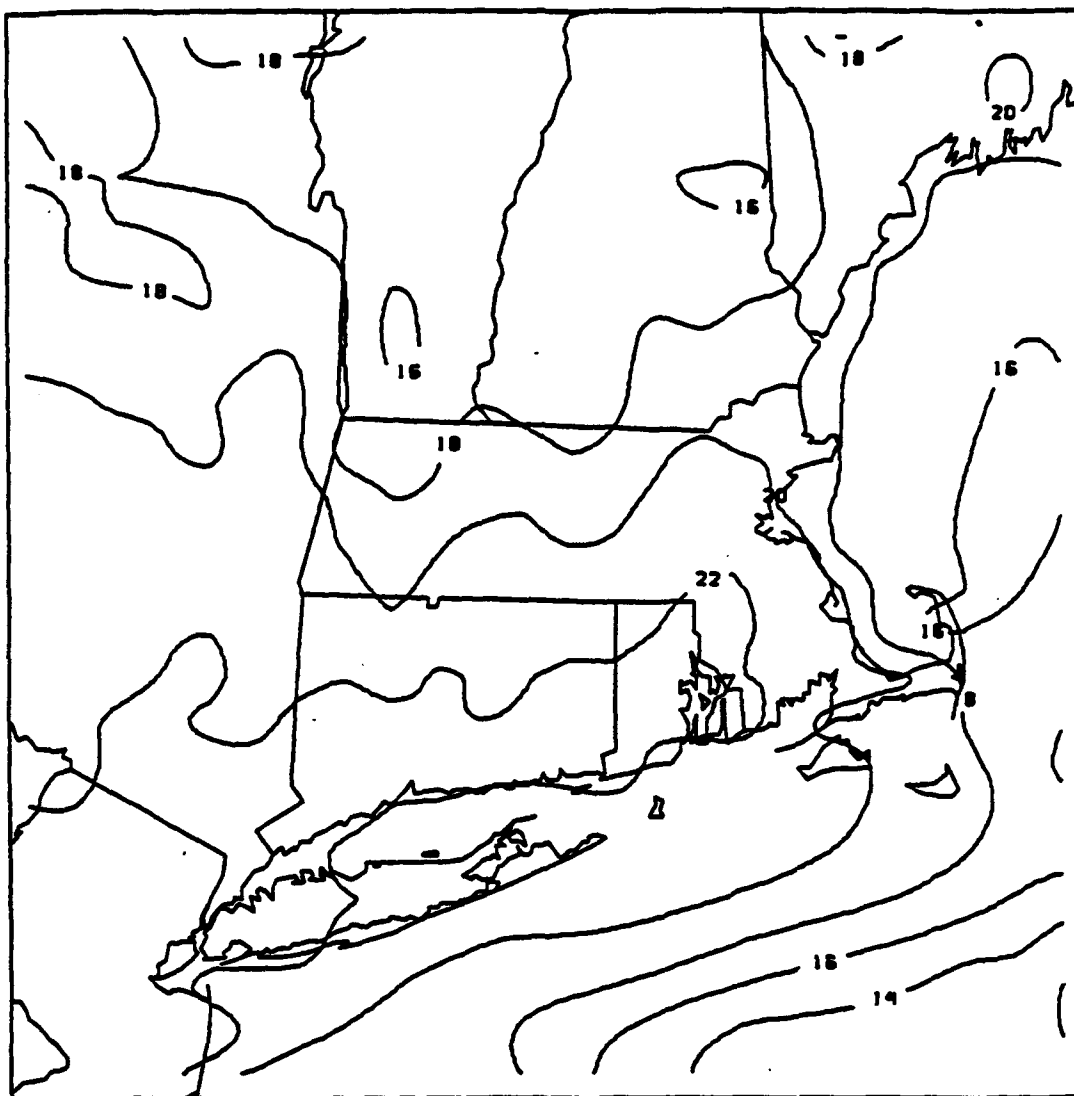


Figure 21. As in Figure 20 except for model run with clouds.

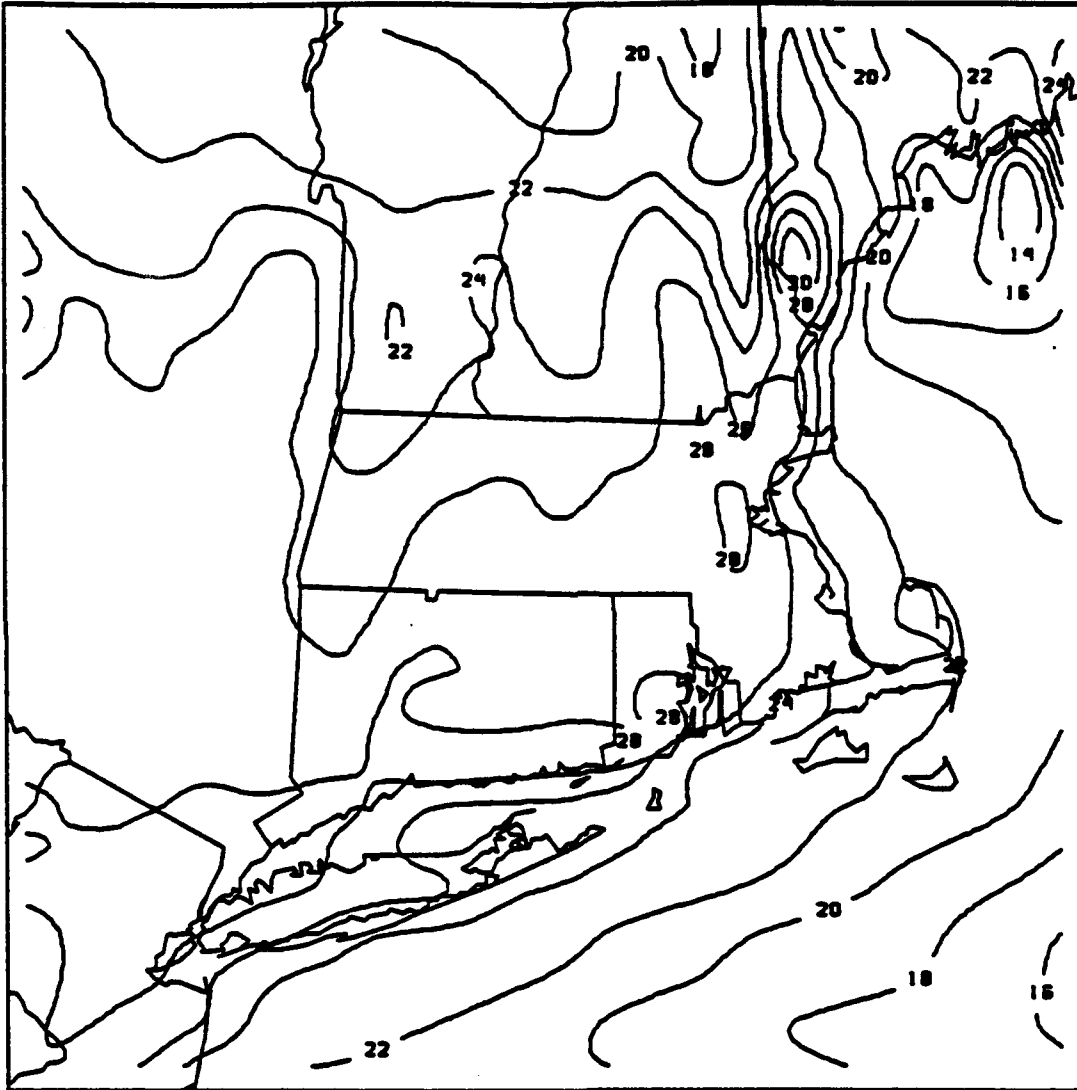


Figure 22. As in Figure 20, except after 10 hours of simulation.



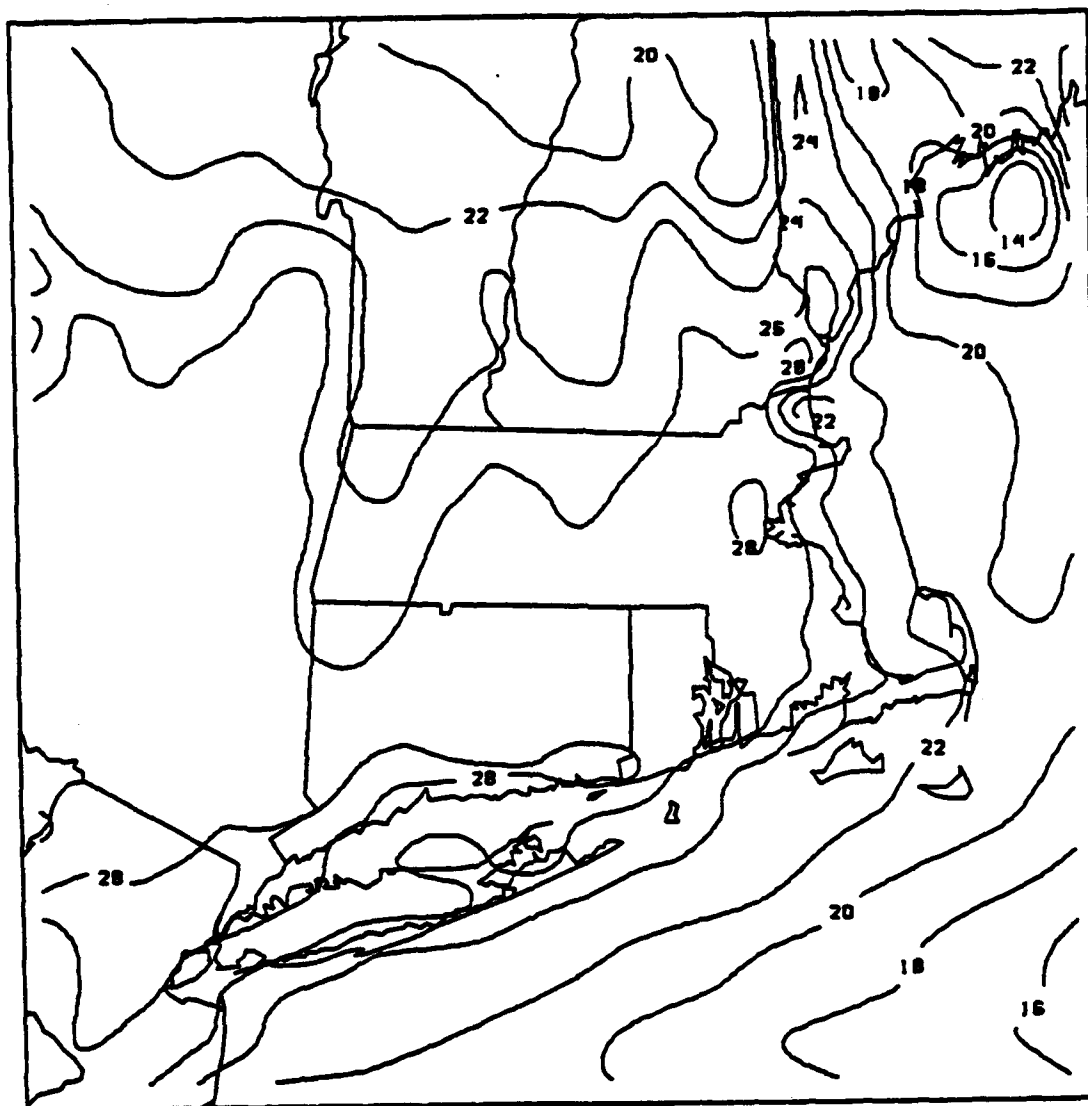


Figure 23. As in Figure 21, except after 10 hours of simulation.

The latent heat released by this condensation is added as heat to the layer.  
The end result is a layer which is still saturated, and so still filled with clouds.  
This process is iterative in its exact form, but the present formulation allows the model to calculate the correct amount of precipitation in one step.  
The formula is:

$$\text{delta\_q} = (q - q_s) / (1.0 + q_s L^2) / (C_p R T^2)$$

$q_s$  = saturation mixing ratio

$L$  = latent heat of evaporation

The results from correcting a supersaturation of 110% at various pressure levels are shown in Table 1.

Table 1.

Pressure of 850 mb		
T(initial)	T(final)	RH(final)
288.0000	289.0275	0.9976436
283.0000	283.8901	0.9981272
278.0000	278.7502	0.9985127
273.0000	273.6127	0.9988222
268.0000	268.4833	0.9990711
263.0000	263.3672	0.9992695
258.0000	258.2686	0.9994280
253.0000	253.1891	0.9995554
248.0000	248.1284	0.9996589
243.0000	243.0841	0.9997423

Table 1 (cont.)

Pressure of 700 mb

T(initial)	T(final)	RH(final)
278.0000	278.8194	0.9981317
273.0000	273.6797	0.9985143
268.0000	268.5446	0.9988269
263.0000	263.4202	0.9990816
258.0000	258.3117	0.9992848
253.0000	253.2221	0.9994499
248.0000	248.1522	0.9995809
243.0000	243.1005	0.9996835
238.0000	238.0641	0.9997675
233.0000	233.0395	0.9998327

Pressure of 500 mb

T(initial)	T(final)	RH(final)
268.0000	268.6556	0.9982919
263.0000	263.5203	0.9986610
258.0000	258.3964	0.9989609
253.0000	253.2893	0.9992057
248.0000	248.2023	0.9993997
243.0000	243.1357	0.9995527
238.0000	238.0876	0.9996709
233.0000	233.0544	0.9997652
228.0000	228.0326	0.9998366
223.0000	223.0189	0.9998896

It is obvious from this table that the routine produces almost exactly the correct amount of change in temperature and humidity to leave the atmosphere saturated.

## 7. Precipitation Case Study

We have used the April 1, 1993 case to examine the effects of including clouds and precipitation in the model. The resulting simulation is NOT very good in terms of forecasting what actually happened. We found that the boundary conditions we were using in the middle of the 24 hour simulation were very poor, due to noisy and missing data. However, the effects of including precipitation in the model can be illustrated nonetheless.

The weather conditions on this day were characterized by a nearly stationary, heart-shaped area of low pressure situated southwest of New England. Figure 24 shows the National Weather Service's NGM model initialization for 12 UTC on 1 April, which shows this area of low pressure. Along the coast, a coastal front developed, extending northeast from New York City, just east of Portsmouth, NH, and along the Maine coast.

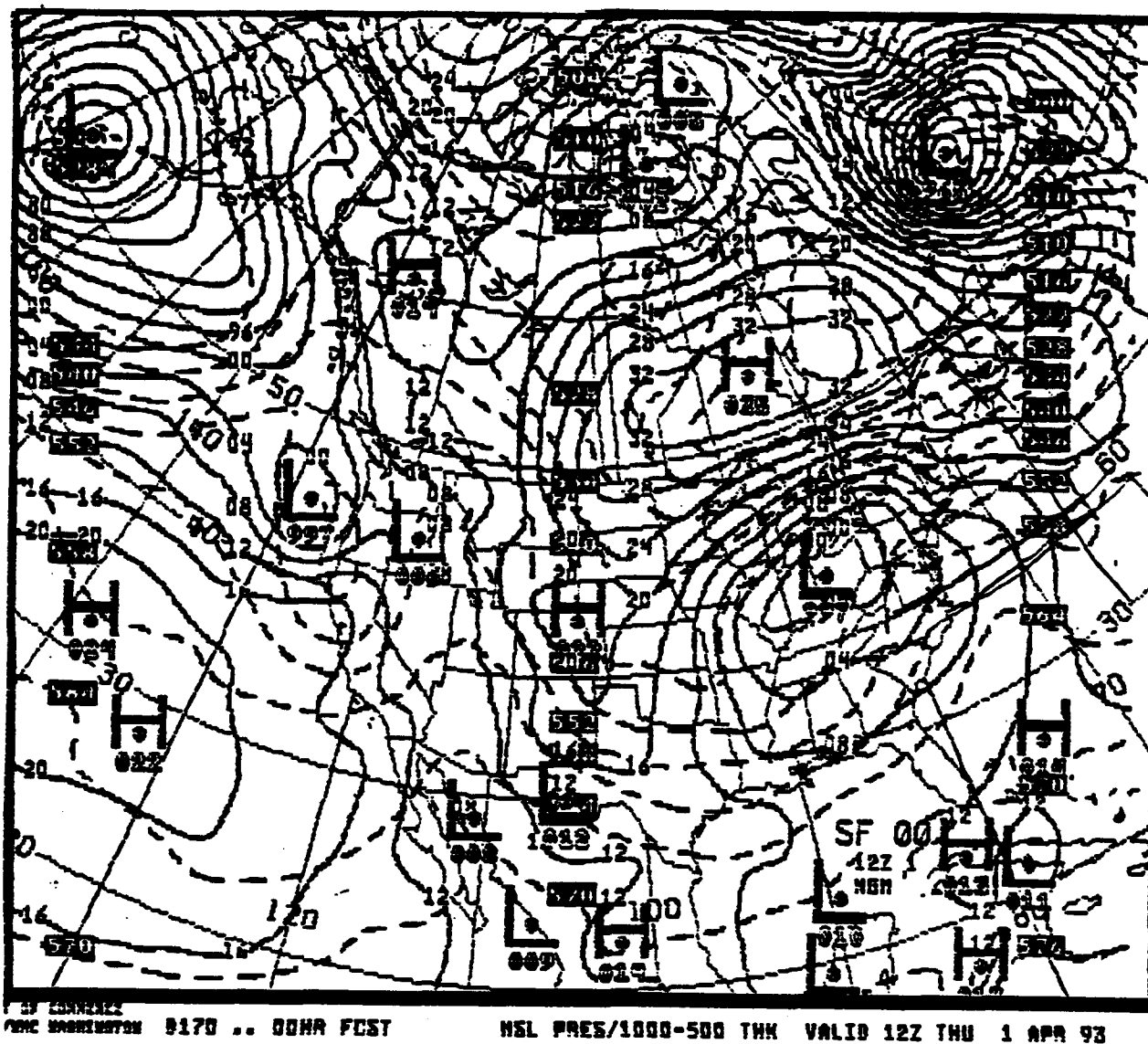


Figure 24. NGM model initialization for 12 UTC, 1 April, 1993. Solid lines are sea-level pressure in mb, dashed lines are 1000-500 mb thickness in dm.

Precipitation developed along and around this frontal zone, as shown in Figures 25 and 26. By 06 UTC on 2 April, the winds along the coast had backed more to the north, and the precipitation became lighter and more spotty.

The 6 hr model forecast with clouds and precipitation produced a sea-level pressure field at 18 UTC as shown in Figure 27. Comparing this with the actual 18 UTC field in Figure 28, one can see that the model failed to simulate the backing of the winds along the coast, although the pressure field shape is reasonably duplicated. Since the winds in Figure 28 are at about 5 m, and the winds in Figure 27 are at the middle of the boundary layer (up to 500m in height), one might expect that the two fields would not be well-correlated. The model temperature field in Figure 29 compares well with reality (Figure 30) in shape, but is about 2 °C too warm.

At 06 UTC on 2 April, the model forecast is worse. As 12 hours earlier, the sea-level pressure field (Figure 31) has the correct shape, but the winds lack the northerly components seen in Figure 32. The temperatures in the model are too cold at this point (compare Figure 33 with Figure 34), and there is evidence of noise in the model forecast in the northeast.

The precipitation and clouds also show some errors. At 18 UTC, the clouds, as shown in Figure 35 by the dashed lines, extend over most of the region. Precipitation, however, only fell on the ridges; there is no accumulation over eastern Massachusetts. By 06 UTC, Figure 36 shows that the model forecast has clearing over the southern half of New England, although Figure 26 shows that this region actually stayed cloudy. Precipitation has continued to accumulate in the model only where topographical forcing is operating, despite the fact that precipitation was observed all along the coastal plain of southern New England (see Figure 26).

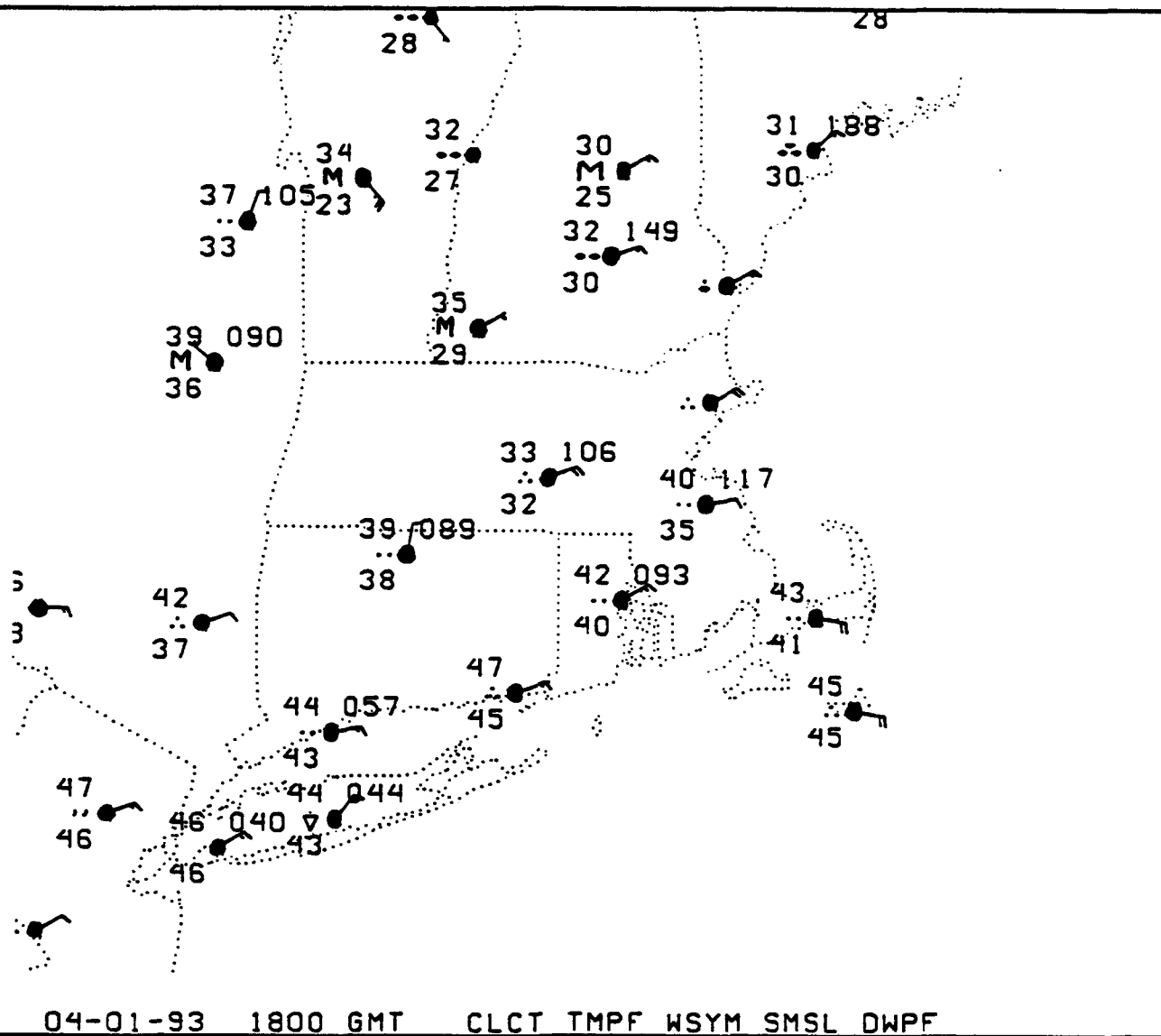


Figure 25. Plot of surface airways observations at 18 UTC, 1 April 1993.  
Data is plotted in conventional notation.





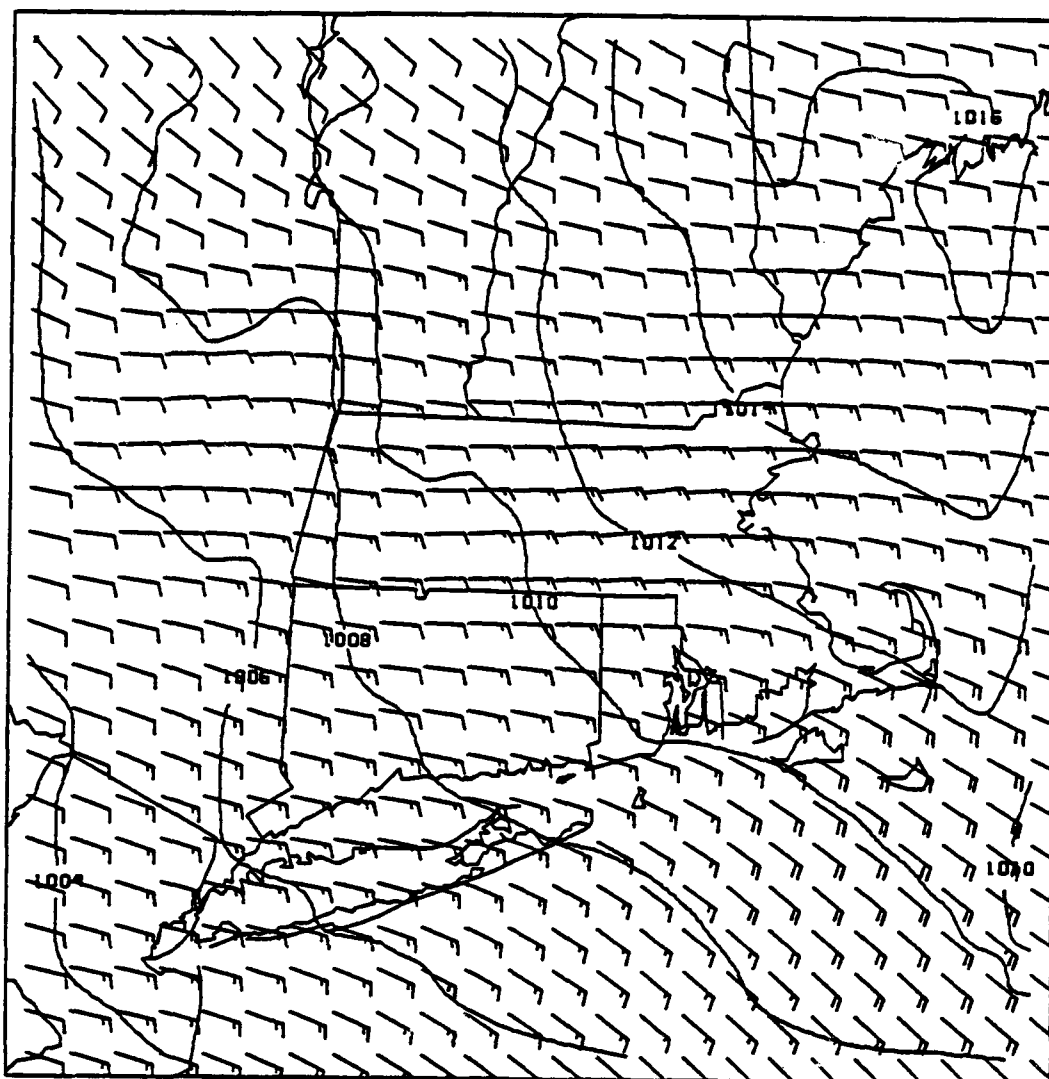


Figure 27. Output from model (with precipitation and clouds) on fine grid mesh, for 18 UTC, 1 April 1993. Solid lines are sea-level pressure in mb, and winds are in knots.

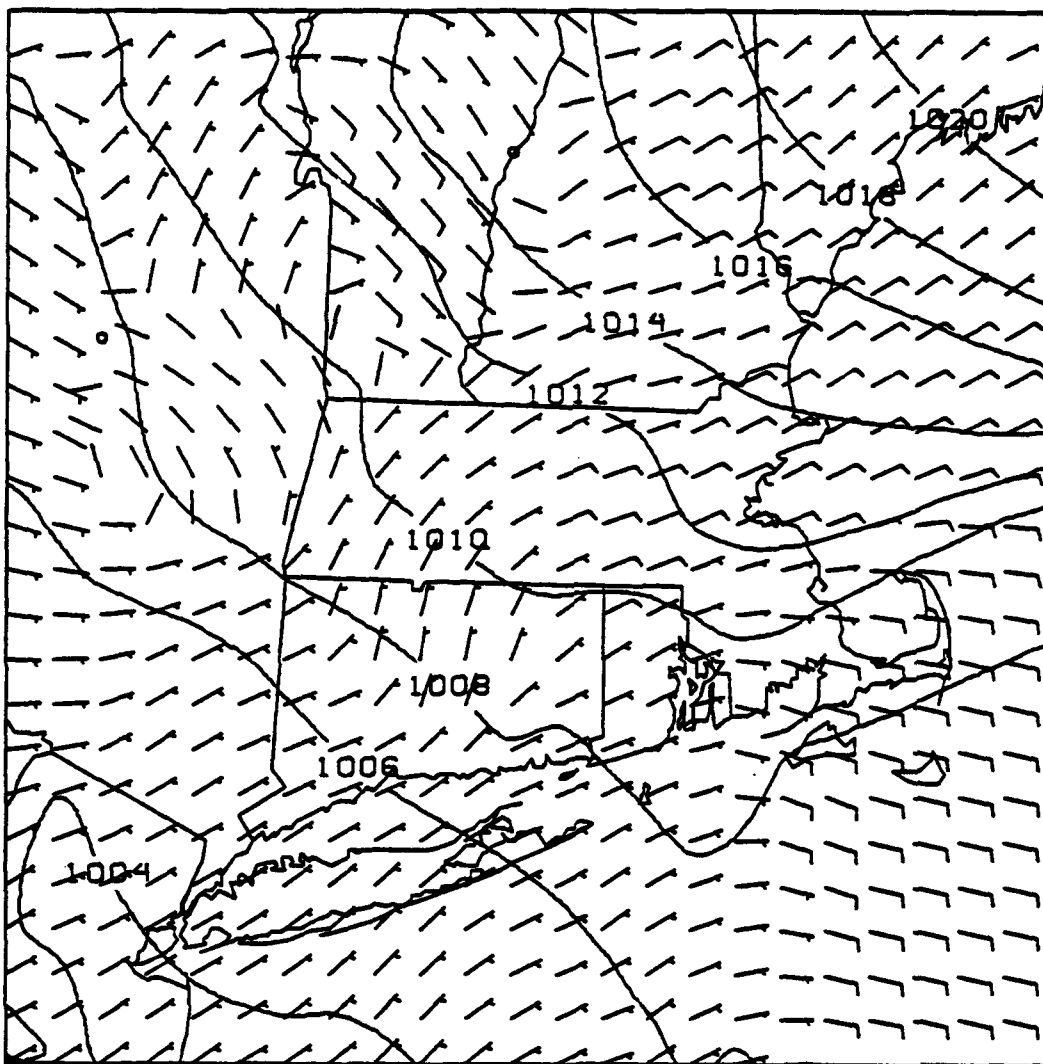


Figure 28. As in Figure 27, except for actual data. Winds are plotted in m/s.



Figure 29. As in Figure 27, except solid lines show temperatures in degrees C.

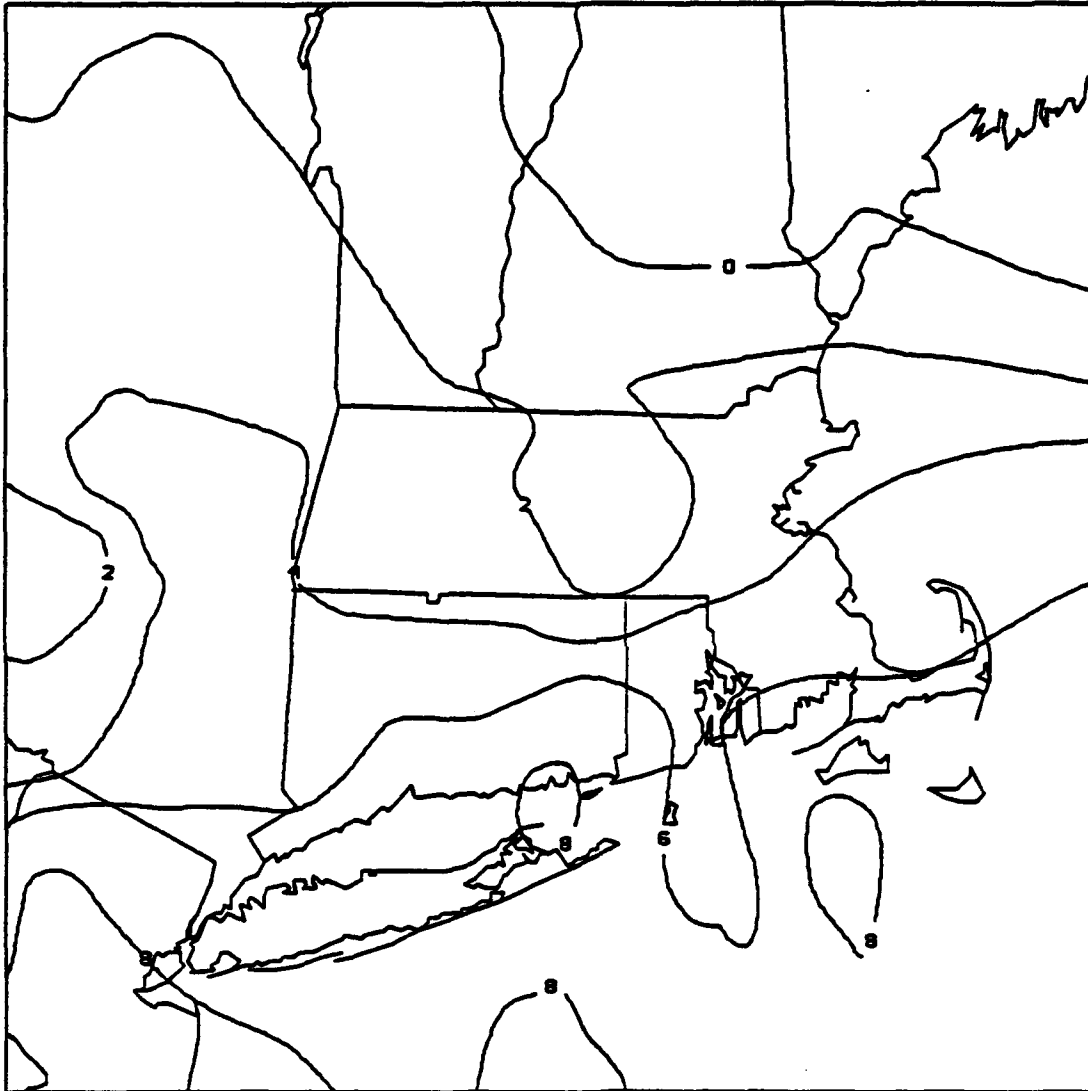


Figure 30. As in Figure 29, except showing actual data.

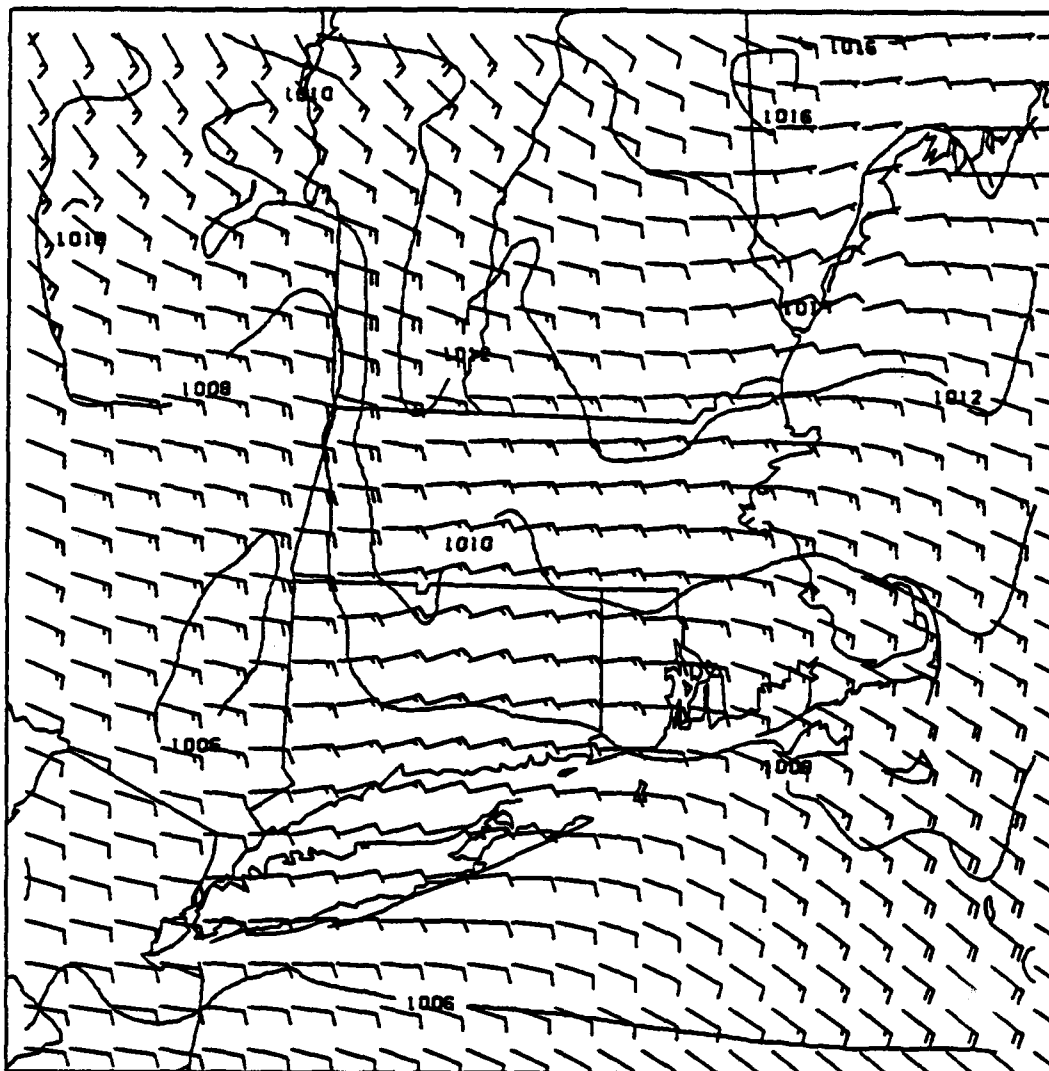


Figure 31. As in Figure 27, except for 06 UTC, 2 April 1993.

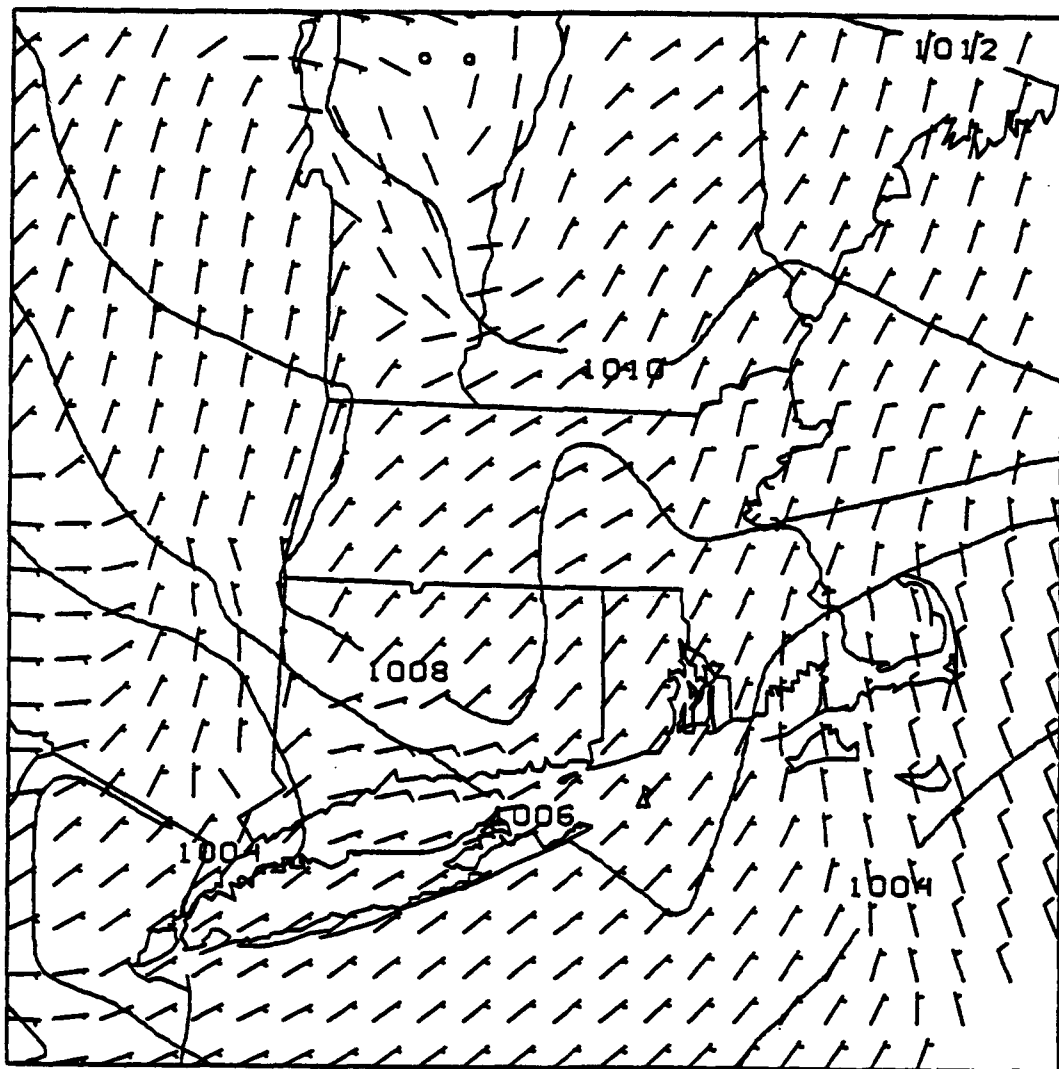


Figure 32. As in Figure 28, except for 06 UTC, 2 April 1993.

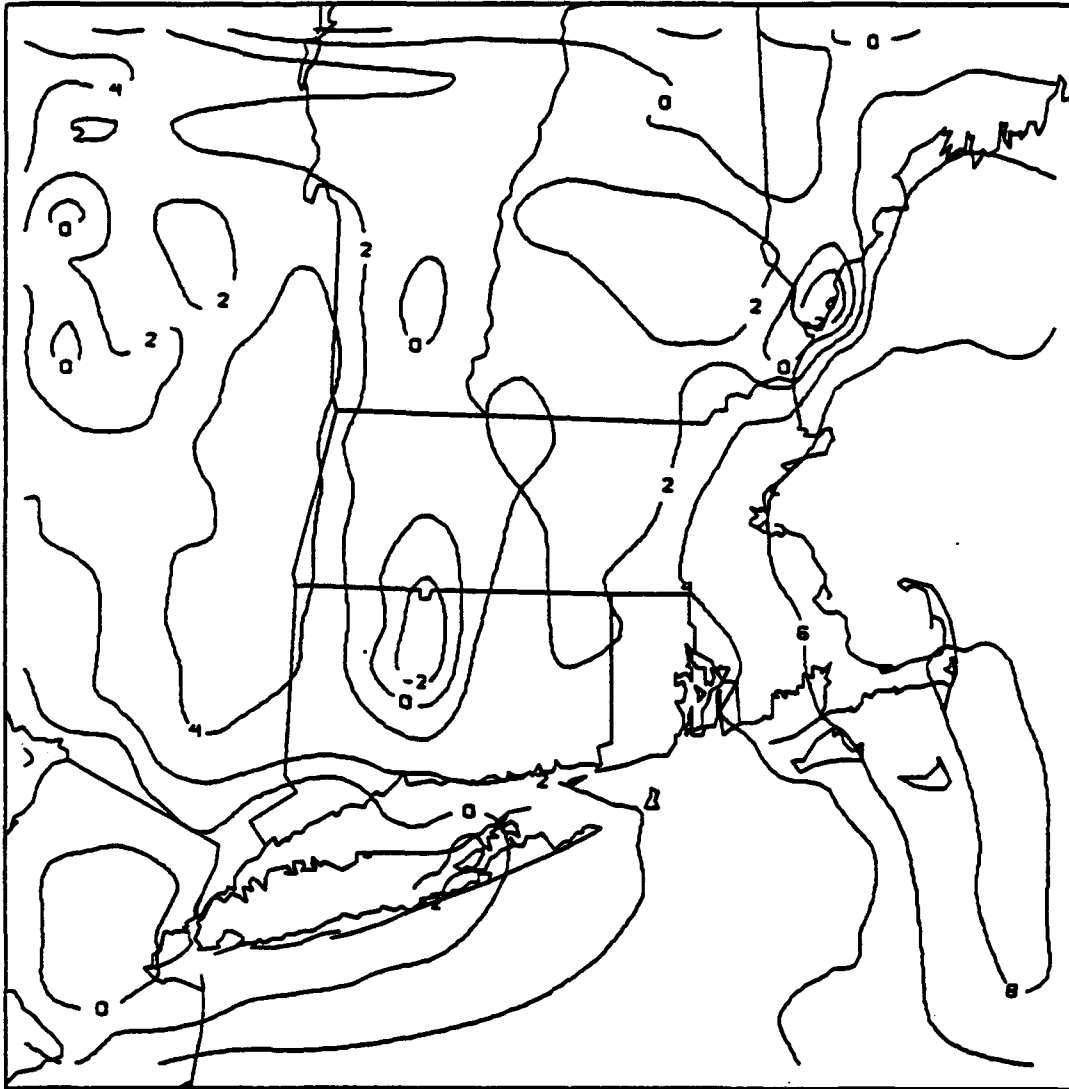


Figure 33. As in Figure 29, except for 06 UTC, 2 April 1993.

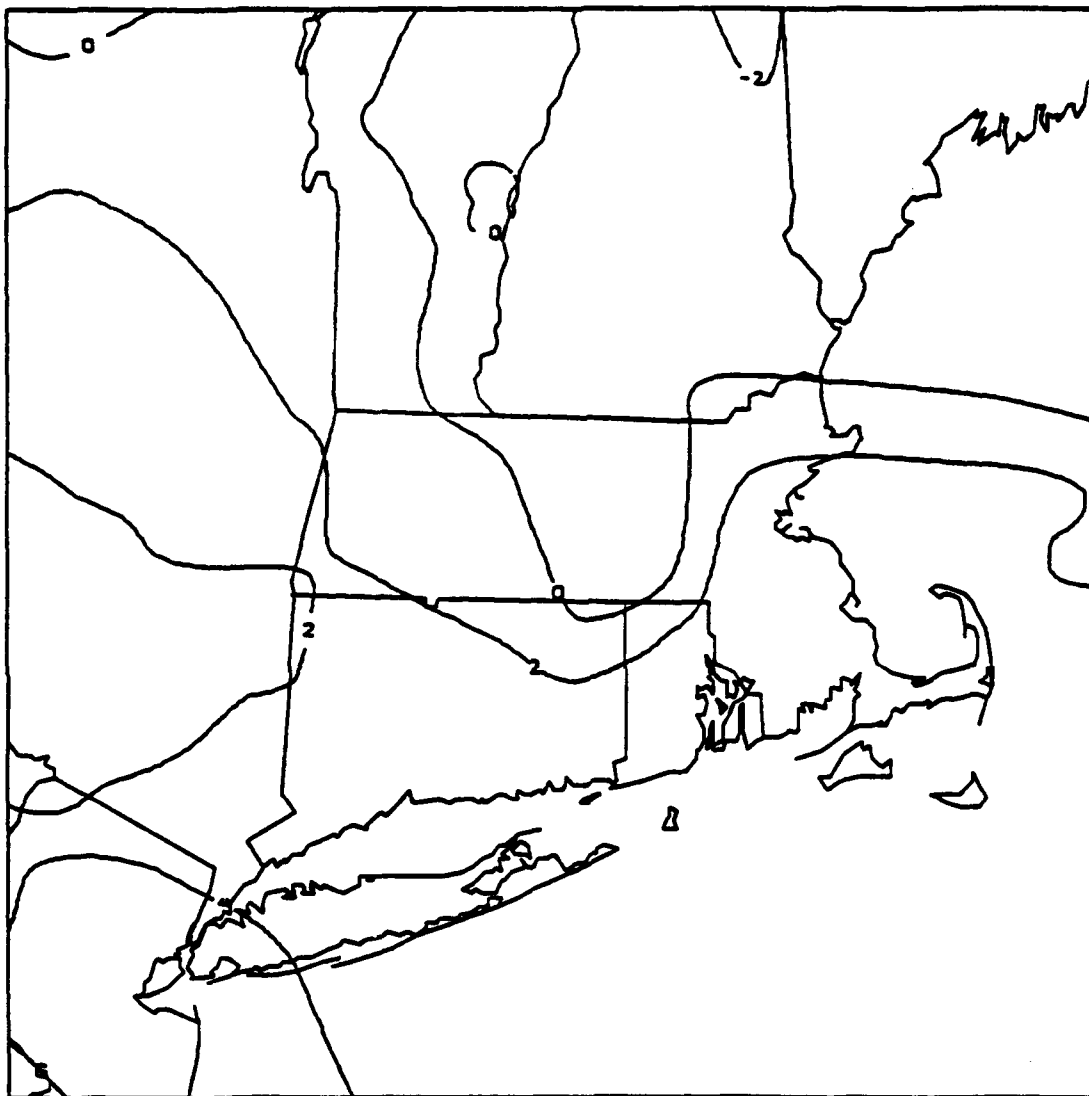


Figure 34. As in Figure 30, except for 06 UTC, 2 April 1993.



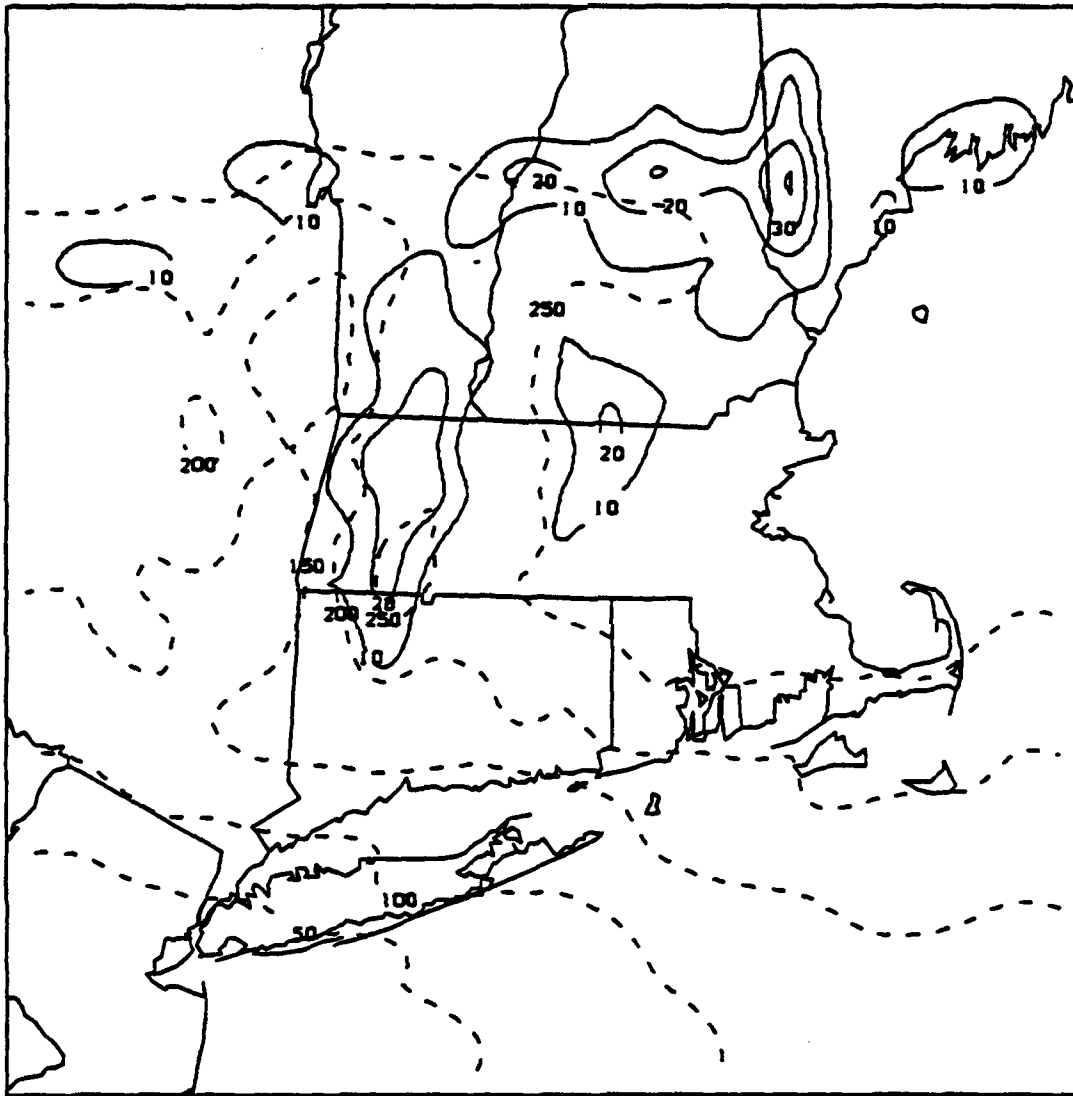


Figure 35. Clouds and precipitation from model at 18 UTC, 1 April 1993. Solid lines are accumulated (since model initialization) precipitation in mm, dashed lines are the sum of three levels of relative humidity.

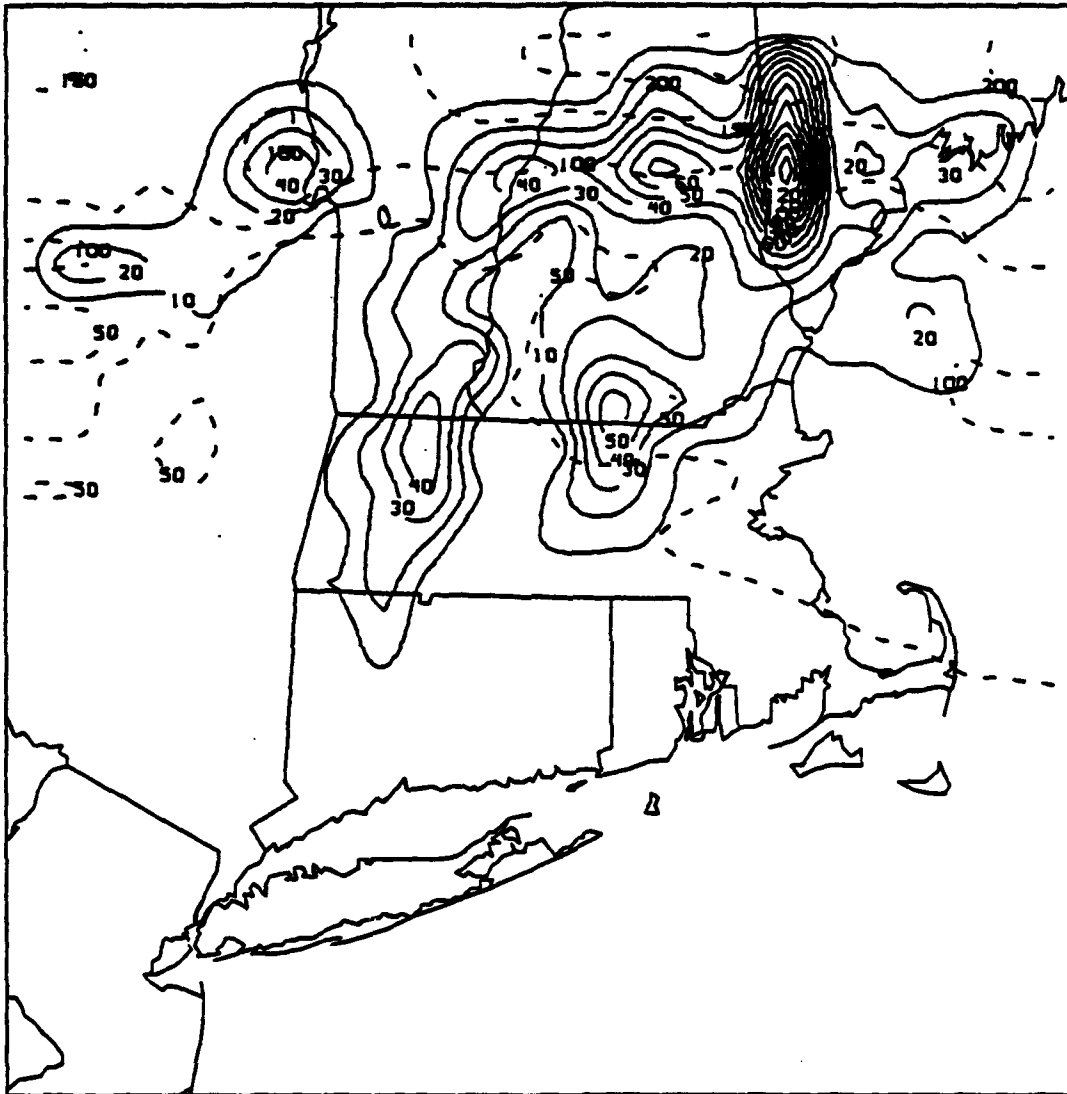


Figure 36. As in Figure 35 except for 06 UTC, 2 April 1993.

When precipitation is removed from the model, along with the latent heat release which accompanies it, very little change appears in the model forecast. The temperature patterns by 18 UTC (shown in Figure 37) are essentially unchanged, although the run without precipitation is a little colder in spots. There is no observable change in either the sea-level pressure field or the winds.

When clouds are removed as well, the change is larger, as expected. Even in the south, where clouds were only present during the morning in the model run with precipitation, the temperatures are significantly warmer in the run without clouds (compare Figure 38 with Figure 29). The sea-level pressure field is also different, although not as much different as one might expect (compare Figure 39 with Figure 27).

## 8. Conclusions and Future Work

We are a little unhappy with the performance of the model in this case; it was unable to produce the coastal front precipitation which was crucial to the weather that day. Additionally, we would expect the model to be able to reproduce such a feature. However, in view of the poor quality of the boundary conditions in this case, and based on preliminary runs with somewhat improved conditions, we are hopeful that the model will be able to do a better job with similar cases.

As far as the inclusion of precipitation in the model, the behavior was noticeable, but not huge, suggesting that the model is robust to handle even relatively large amounts of precipitation (as much as 50 mm) without suffering attendant noise problems.

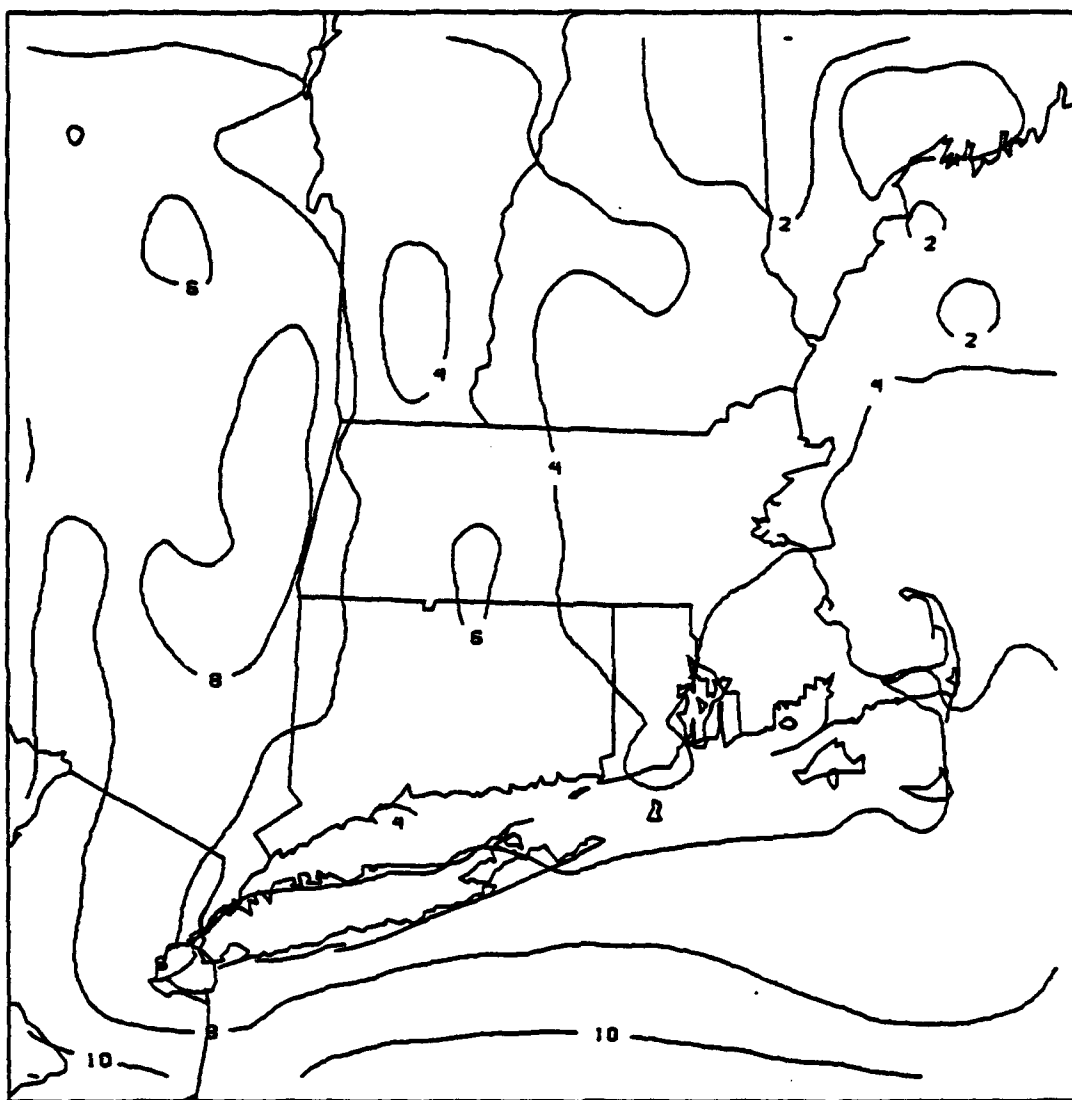


Figure 37. Output from model without precipitation on fine grid mesh, for 18 UTC, 1 April 1993. Solid lines are temperatures in  $^{\circ}\text{C}$ .

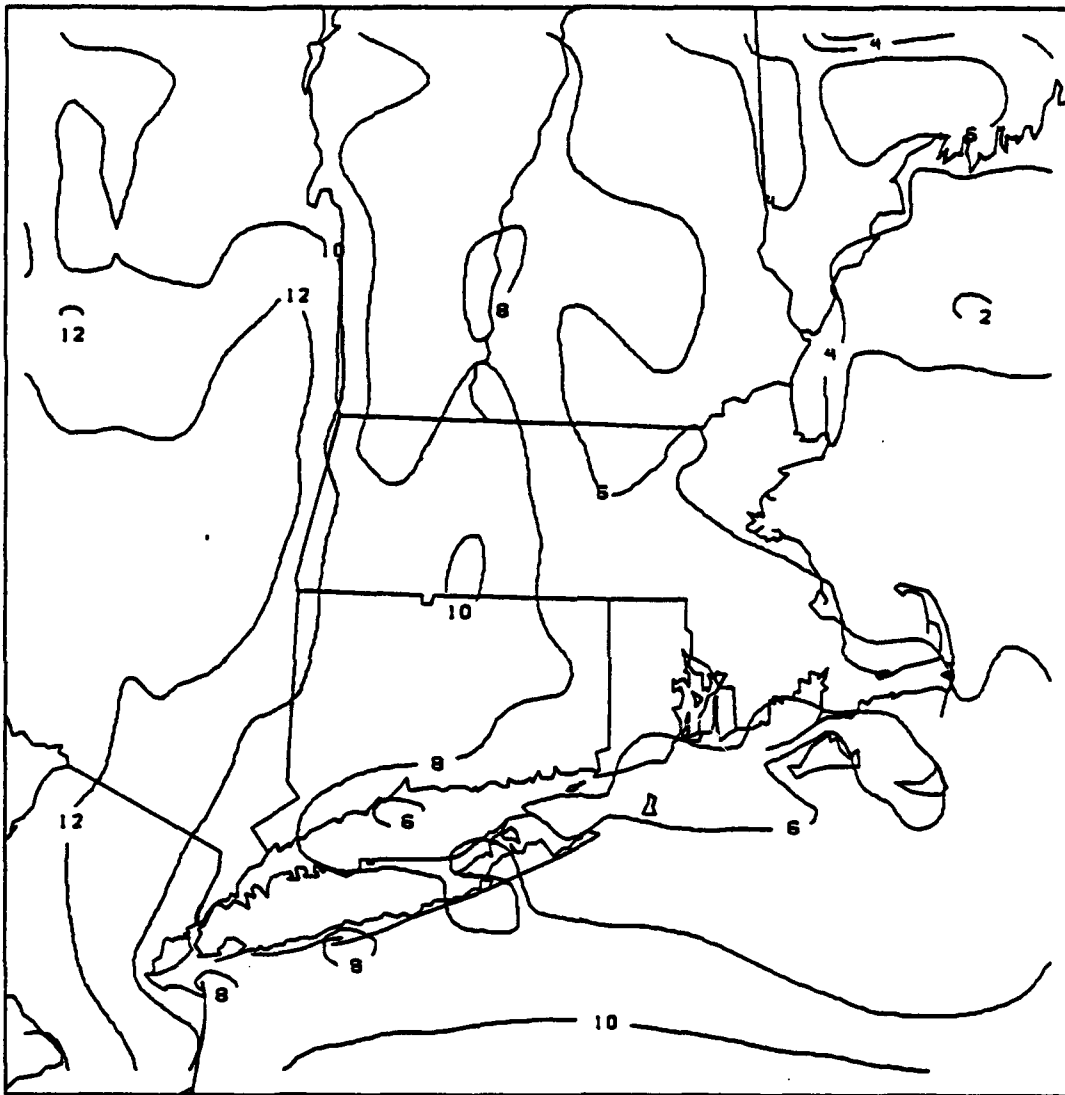


Figure 38. As in Figure 37, except for model without clouds or precipitation.

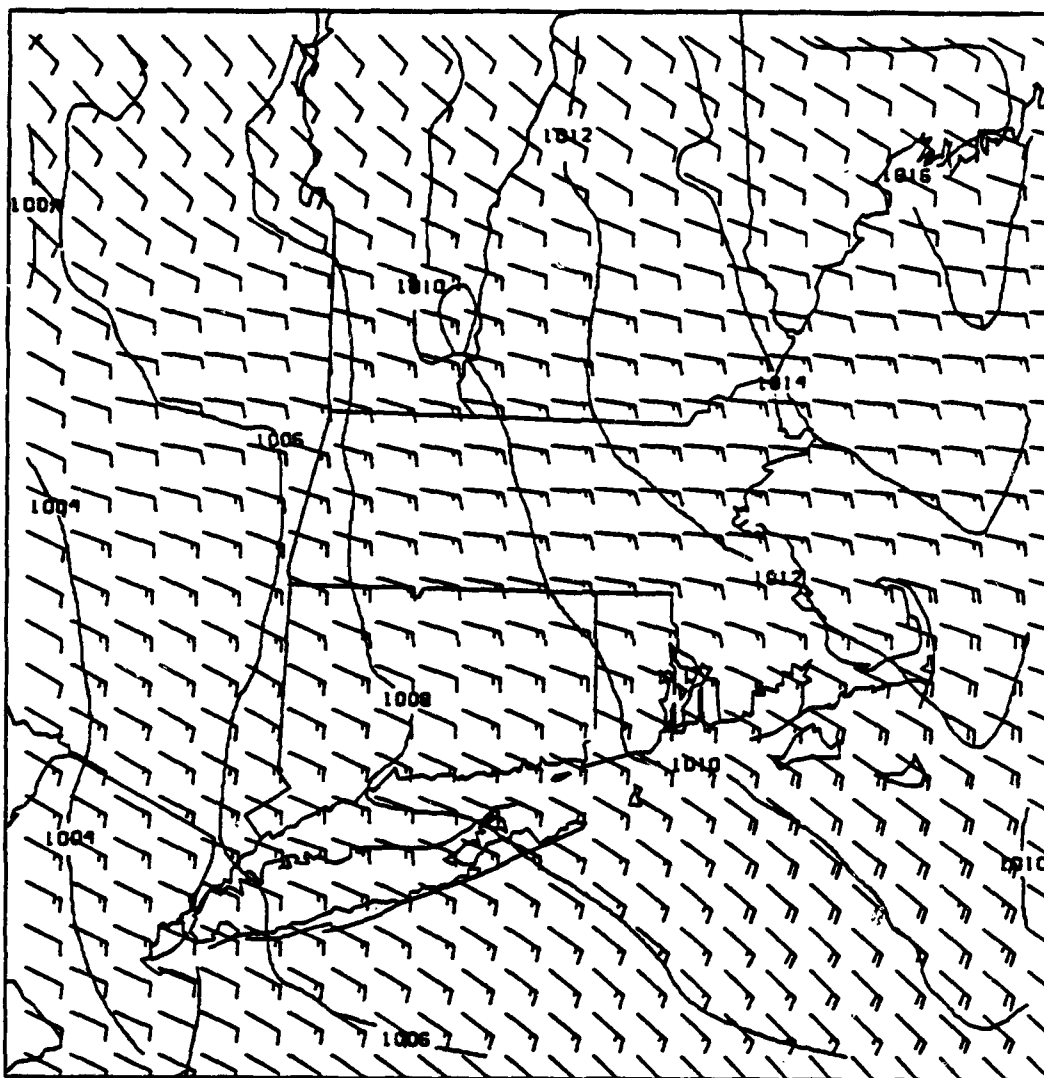


Figure 39. As in Figure 38, except solid lines are sea-level pressure in mb, and winds are shown in knots.

We are in the process of adding a more sophisticated microphysics package (Modica, personal communication), and plan to do some experiments with different approaches to the surface energy balance (Colby, 1983 and Pan, 1990). Finally, we have tried running the model with 12 layers instead of 6, and are in the process of determining the differences between these simulations.

## 9. References

Colby, F.P., Jr., and K.L. Seitter, 1992: Short term weather forecasting in real time in a base weather station setting. Scientific Report No. 1, Phillips Laboratory, PL-TR-92-2341.

Colby, F.P., Jr., 1983: A simple one-dimensional boundary layer model for both stable and unstable conditions. Final Report to AFGL-SCEEE Geophysics Scholar Program, sponsored by the Air Force Office of Scientific Research.

Pan, H-L., 1990: A simple parameterization scheme of evapotranspiration over land for the NMC medium-range forecast model. *Mon. Wea. Rev.*, 118, 2500-2512.